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CREW ESCAPE CRITERIA FOR TWO STAGE RECOVERABLE AEROSPACE VEHICLES

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October 1964

AF Flight Dynamics Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 1362, Task No. 136203

(Prepared under Contract No. AF33(615)-1536 by General Dynamics Astronautics,
a Division of General Dynamics Corporation, San Diego, California;
C. J. Cohan, C. G. Place, H. T. Webster and F. Wendzel, authors)

NOTICES

FOREWORD

This report describes the work accomplished in an investigation of crew escape criteria for manned recoverable launch vehicles by General Dynamics/Astronautics, San Diego, California, under Air Force Contract Number AF 33(615)-1536. The program was conducted between 10 May 1964 and 1 September 1964 for the Recovery and Crew Station Branch of the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems command, United States Air Force, Wright-Patterson Air Force Base, Ohio. Mr. J. M. Peters was the program monitor for the Laboratory.

The objective of the program was to investigate, define, and evaluate the unique problems involved in the initiation and separation phases of escape for two stage manned, recoverable launch systems having separated crew compartments. This is a part of a continuing effort to obtain escape systems design criteria under Project 1362, "Crew Escape for Flight Vehicles", and Task 136203, "Aeronautical Crew Escape Techniques".

General Dynamics/Astronautics Project Leader was Mr. C. J. Cohan. Other key Astronautics personnel assigned to the project were Mr. C. G. Place, trajectory analyses, Mr. G. T. Webster, design and hazards, and Mr. F. Wendzel, detection and initiation. The contractor's report number is GD/A-DCB-64-072.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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ABSTRACT

Previous studies have investigated escape from aerospace vehicles in the general aspects of escape concepts, configurations, systems and performance for single crew compartments. At hand is the concept of two stage manned recoverable aerospace vehicles with a crew compartment in each stage. In this study the detection, initiation and separation phases of escape were investigated to determine the unique problems, if any, in these phases resulting from the presence of two separated crew compartments. Possible two stage manned aerospace vehicles were classified as to configuration and mission. The basic mission was an orbital mission, and the basic configuration classes were vertical take-off and landing (VTOHL) and horizontal take-off and landing (HTOL). Generalized hazards analysis studies were made for each configuration class considering system hazards and mission effects. It was determined that crew escape requirements existed at any time in the mission. Escape concepts ranging from ejection seats to fully recoverable capsules were reviewed for applicability to the present problem with the fully recoverable capsule being selected. No unique problems were found in the area of sensors required for the detection task. A combination manual/automatic escape initiation system was selected as the most promising for these advanced concept vehicles. A cockpit malfunction status display and emergency control console was conceptually designed. This system, called the Malfunction Warning Display, would be in each compartment and prior to staging each compartment would monitor boost performance, making the most use of the flexibility and decision making capability of the men in each crew compartment. Guidelines for jurisdiction (authority to command an ejection) and precedence (priority or order of jurisdiction) have been established. Separation trajectory characteristics were investigated leading to the establishment of crew compartment location and ejection sequencing criteria. The conclusion of this study is that there are no difficult problems associated with crew escape for two separated crew compartments. The unique problems which might be better classed as unique considerations for two crew compartment escape are the distribution of the sensed malfunction information, the jurisdiction and precedence of escape initiation, and the location and sequencing characteristics.

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SECTION 1

INTRODUCTION

Previous Air Force studies have investigated escape in the general aspects of escape concepts, configurations, systems and performance for aerospace vehicles having a single crew compartment. Present aerospace vehicle studies are considering two stage vehicles in which each stage has a crew or manned payload.

It was the purpose of the present study to investigate this new situation to determine if there are any unique problems involved in the initiation and separation phases of escape resulting from the fact that there are two separated manned compartments. The investigation consisted of four main tasks as follows:

1. Definition and classification of the types of manned aerospace vehicles and missions to be considered.

2. Determination of hazards and conditions requiring escape.

3. Determination of those problems of detection, initiation, separation and escape concepts which are unique due to the presence of two separated crew compartments.

4. Evaluation of proposed solutions to any discovered problems.

The nature of the study was such that it drew heavily on information determined in previous one stage aerospace vehicle escape studies such as those documented in References 1 through 5.

The study was conducted in such a manner that the results described herein are general criteria rather than criteria limited to specific designs and should therefore serve as a guide for escape analysis of any two stage manned vehicle.

Manuscript released by the authors September 1964 for publication as an RTD Technical Documentary Report

SECTION 2

CONFIGURATION AND MISSION DEFINITION

The first step in the investigation was the definition and classification of manned two stage vehicles according to configuration and performance. It was the purpose of this phase of the study to reduce the large number of possible configurations and missions to representative ones on which to base the primary escape investigation. In performing this phase a large number of proposed configurations and missions were reviewed. Information was obtained from government studies, trade journals and contractor in-house studies. In order to present the study results in an unclassified report the specific configurations and missions which were reviewed are not presented.

2.1 CONFIGURATION DEFINITION

The vehicles which were reviewed in this phase of the study were two stage, manned recoverable vehicles having two separate crew compartments. For the investigation, each stage was assumed to have a three-man crew, however, the number of crew members could vary from one to five for each stage without affecting the results of this study. Crew escape techniques for more than five persons would probably impose such large weight and structural restrictions that the escape technique would be complete vehicle recovery. Two stage recoverable aerospace vehicles can be reduced to two basic configuration classes. These are the Vertical Take-Off, Horizontal Landing (VTOHL) and the Horizontal Take-Off, Horizontal Landing (HTOL) vehicles.

2.1.1 VERTICAL TAKE-OFF, HORIZONTAL LANDING (VTOHL). The VTOHL vehicle class is one in which vehicle recovery provisions for each stage are added to the basic body of revolution. These recovery provisions can range from fixed wings to parachutes. The mode of recovery has little effect on the escape considerations involved in this study. A fixed wing recovery system was selected for the nominal VTOHL configuration of this study.

VTOHL vehicles can be further classified as to propulsion mode. The boost propulsion system can be either liquid or solid rockets or a combination in which the main propulsion mode is a liquid rocket and solid rockets are used for additional thrust. Both liquid and solid rockets can be further classified by propellant type. In addition to the boost propulsion mode, turbojet engines are generally required for flyback and landing. Figure 1 presents a sketch of a typical VTOHL vehicle using liquid oxygen-liquid hydrogen propellant. Also shown in Figure 1 is a typical propellant weight breakdown for both stages.

An additional classification of VTOHL vehicles and one that is of particular significance to escape involves the relative location of the two stages. The two basic arrangements are tandem and parallel and are indicated in Figure 2. The tandem arrangement is considered the most likely for the vertical boosted vehicle. The parallel mounted arrangement imposes the most severe requirement on the sequencing of the escape capsule jettisoning because of the proximity of the crew capsules.

2.1.2 HORIZONTAL TAKE-OFF AND LANDING (HTOL). The basic HTOL configuration is one in which the first stage is a winged vehicle. The second stage is recoverable and can either be a winged body vehicle or a lifting body vehicle. For the scope of this study the type of second stage is not significant.

	Stage 1 - Wt. - lbs.	Stage 2 - Wt. lbs.	Total
GTOW	1,573,300	426,700	2,000,000
Performance Oxidizer	1,091,000	260,000	1,351,000
Return Propellant	47,500	5,400	52,900
Performance Fuel	143,000	37,600	180,600
Residual Oxidizer	5,500	4,400	9,900
Residual Fuel	1,000	800	1,800
Stage Wt. - Dry	285,300	118,500	403,800
Number of Crew	3	3	6

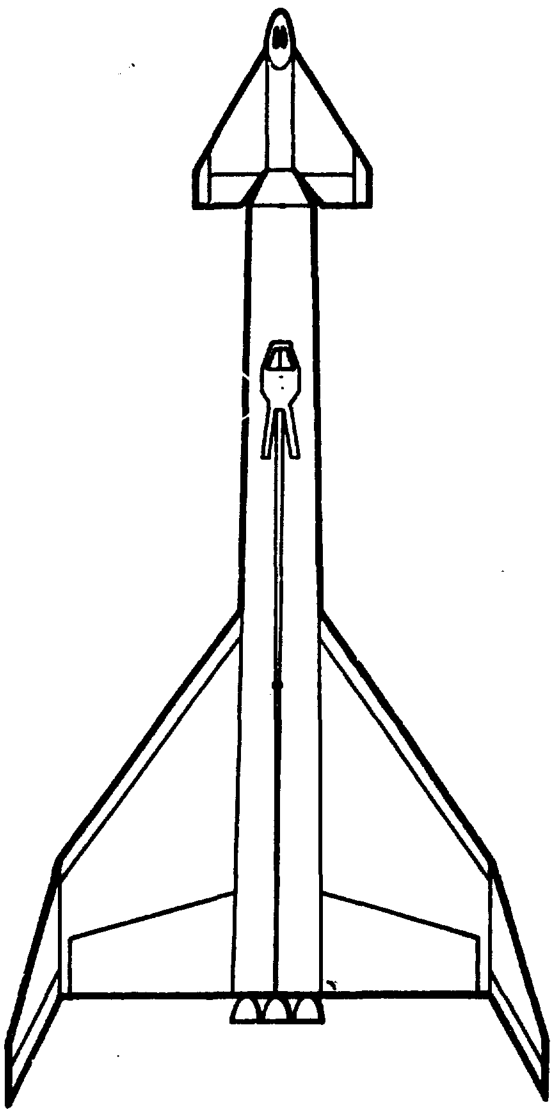

Figure 1. TYPICAL VTOHL CONFIGURATION WITH PROPELLANT WEIGHT BREAKDOWN

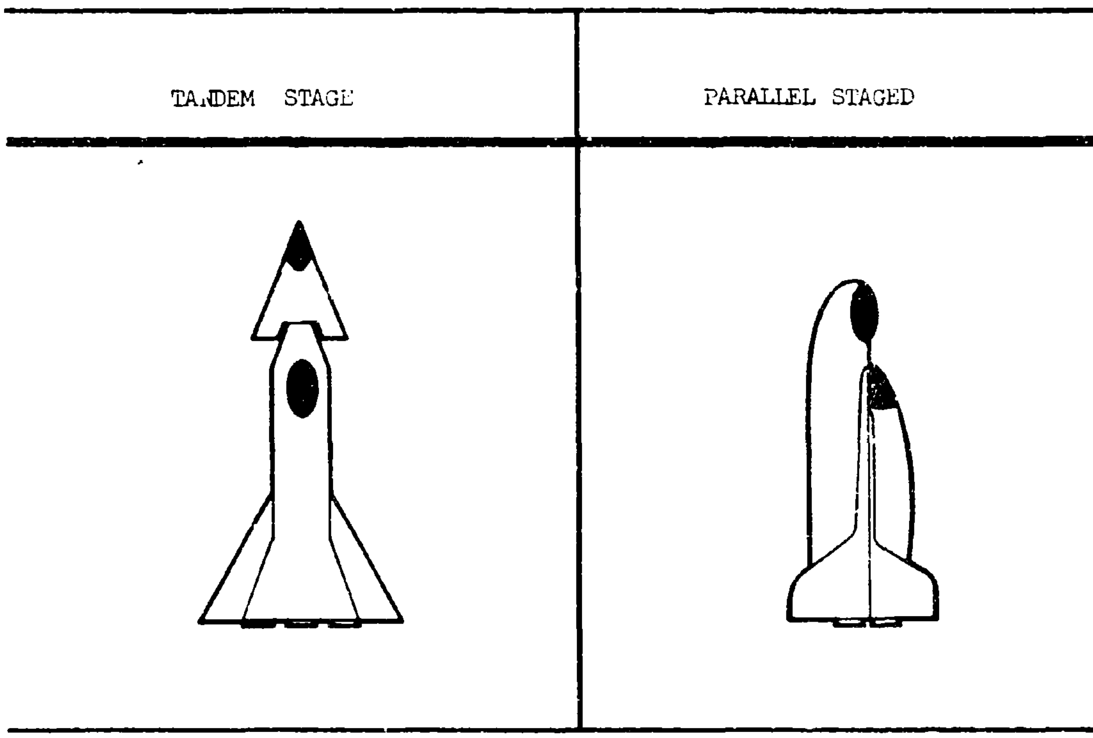

Figure 2. VTOHL STAGE ARRANGEMENTS

As with the VTOHL it is also possible to classify HTOL vehicles as to propulsion mode and propellant. In general, second stage vehicles which are presently envisioned use liquid rocket propulsion with liquid oxygen as the oxidizer and liquid hydrogen as the fuel. There are a number of possibilities in regard to the first stage. The first stage propulsion can be rocket, turbojet, ramjet or various combinations of these. The most probable fuels are JP, RP and liquid hydrogen. For first stage rockets, liquid oxygen is the most likely oxidizer. There are two variations to these propulsion mode, propellant types. The first of these involves the use of a sled for take-off. This arrangement reduces the on-board propellant requirements. The second variation is the air collection vehicle in which all or a portion of the oxidizer for the rockets is collected during the flight.

Figure 3 presents a sketch of a typical HTOL vehicle using rockets in each stage. The first stage is assumed to use liquid oxygen and RP-1 and the second stage liquid oxygen and liquid hydrogen. A typical propellant weight breakdown for each stage is also indicated in Figure 3.

The three most practical arrangements for the two stages of a HTOL vehicle are indicated schematically in Figure 4. The two basic types are tandem and parallel. In the parallel arrangement the second stage can be mounted either on top or on the bottom. The tandem arrangement is considered unlikely due to severe structural penalties involved in mounting the second stage. The penalties of tandem staging are generally more severe for a HTOL than a VTHOL due to the fact that in most cases the HTOL vehicle flies a higher dynamic pressure trajectory. The upper mounted configuration is considered the most likely for the horizontal take-off vehicle, as this arrangement affords crew protection through all regions of the flight envelope. The lower mounted arrangement assumes a high risk for the second stage crew during any flight phases where the vehicle operates near the ground, e.g. take-off and landing.

2.1.3 CONFIGURATION SUMMARY. As can be seen from the above discussion there are a vast number of possible combinations of geometric configuration, propulsion mode, propellants and stage location. In view of this, it is significant to note the problem at hand which is that of crew escape and the relationship of the various configuration parameters to this problem.

The geometric configuration is important since it affects crew location and, in the case of VTOHL versus HTOL, the orientation of escape separation. Except for these effects, the geometric configuration has little or no effect on crew escape.

The propulsion mode is significant primarily through its effect on the escape environment or trajectory time history. There is a secondary effect related to possible hazards by the relative reliability of the various propulsion modes.

The propellants are quite significant since by their very nature they introduce a severe hazard, the possibility of explosion.

The stage location is related to escape since it affects the separation trajectory considerations and also has a small effect on available warning time.

Sections 5 and 6 which discuss escape concepts and escape procedure will note the significance of these configuration parameters in any applicable areas.

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HTOL	Stage 1 - Wt. - lbs.	Stage 2 - Wt. - lbs.	Total
GTOW (lb)	1,182,000	348,000	1,530,000
Performance Oxidizer (LO_2)	672,000	235,500	907,500
Performance Fuel	300,000(RP)	33,700(LH_2)	333,700
Return Propellant (JP)	18,000	1,200	19,200
Residual Oxidizer (LO_2)	11,500	4,000	15,500
Residual Fuel	8,500(RP)	1,600(LH_2)	10,100
Stage Wt. - Dry	172,000	72,000	244,000
Number of Crew	3	3	6

SLED	
Weight (Incl.H-1 Rocket)	150,000 lb.
Liquid Oxygen	131,000
RP-1	59,000
Carried Wt.	1,530,000
Total Weight	1,870,000
Take-Off Speed	400 kts.

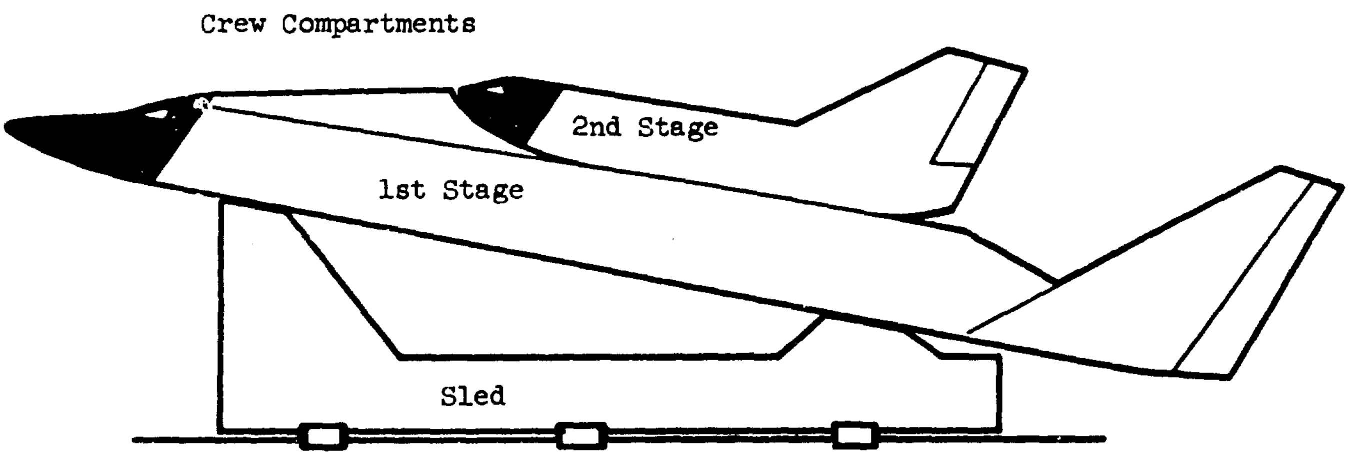

Figure 3. TYPICAL HTOL CONFIGURATION WITH PROPELLANT WEIGHT BREAKDOWN

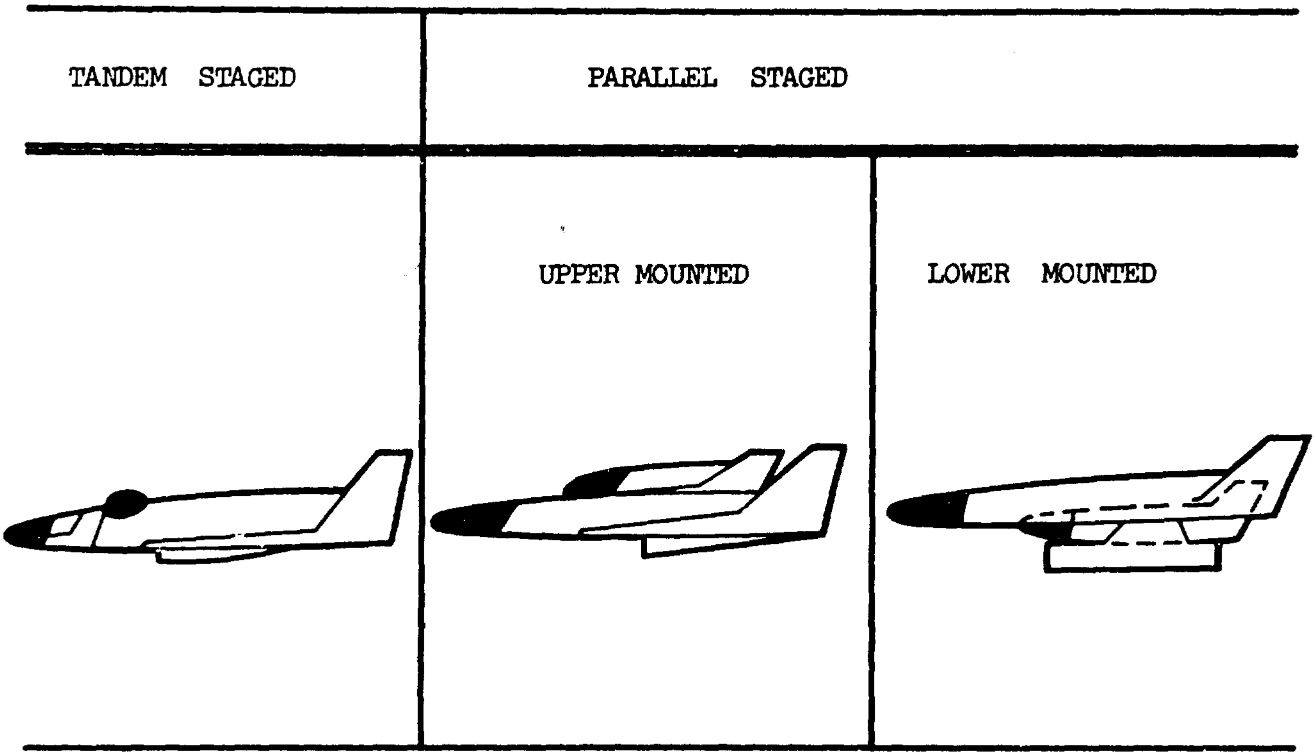

Figure 4. HTOL STAGE ARRANGEMENTS

2.2 MISSION DEFINITION

An orbital mission was selected as the nominal mission for this study. Since the study is directed towards those problems which are unique to providing escape for two separated crew compartments, only those phases of the mission wherein the two stages are together are analyzed.

Although sub-orbital and super-orbital missions are envisioned for future two stage vehicles, the orbital mission includes those regimes of sub-orbital and super-orbital missions where the two vehicles are together and therefore, the results should be valid for the other missions.

As indicated above, the present study was concerned only with those flight regimes in which the two stages are together. In addition to boost this introduces the aspect of non-escape mission abort. There are two possibilities for such an abort. The vehicle may return and land without staging or the vehicle may stage and each stage return and land separately. The method chosen depends on the design criteria of the particular vehicle being considered, since a weight penalty is introduced if provisions are made for landing an unstaged vehicle. The present study would be concerned only with abort trajectories of unstaged configurations.

The trajectory characteristics are significant since they determine the escape environment. Abort trajectories may or may not be more severe than boost trajectories, depending upon abort point and configuration. Since abort trajectories differ only in degree of environment severity and not in basic characteristics, the trajectory analyses phase for the present study was limited primarily to boost trajectories. This assumption would affect the escape corridor definition only for those unstaged abort trajectories which would exceed the most severe boost trajectory. For any specific design study involving abort with an unstaged vehicle the flight corridor would of course have to include the abort trajectory.

A survey of typical manned two stage vehicle missions was made to determine their various boost trajectory characteristics. Trajectory characteristics of the following types of vehicles were considered:

1) HTOL-Horizontal take-off and landing (airbreathing)

2) HTOL-Horizontal take-off and landing (rocket)

3) VTOHL-Vertical take-off-horizontal landing (rocket)

The objective, in terms of crew escape, was to determine a corridor of possible escape points. The corridor was utilized in conducting an investigation of vehicle characteristics during separation at various atmospheric conditions.

Figure 5 is the selected escape performance envelope. It is a flight corridor which bounds the vehicle missions investigated and is the region of interest for escape in the present study. The envelope has been divided into regions applicable to rocket boosters and regions applicable to airbreathing vehicles. The division indicated in Figure 5 is of course not absolute but qualitative. This information in conjunction with the angle of attack and flight path angle characteristics served as input to the investigation of separation trajectory characteristics which are discussed in Section 6.

Figures 6 and 7 present typical trajectory characteristics for VTOHL and HTOL vehicles respectively.

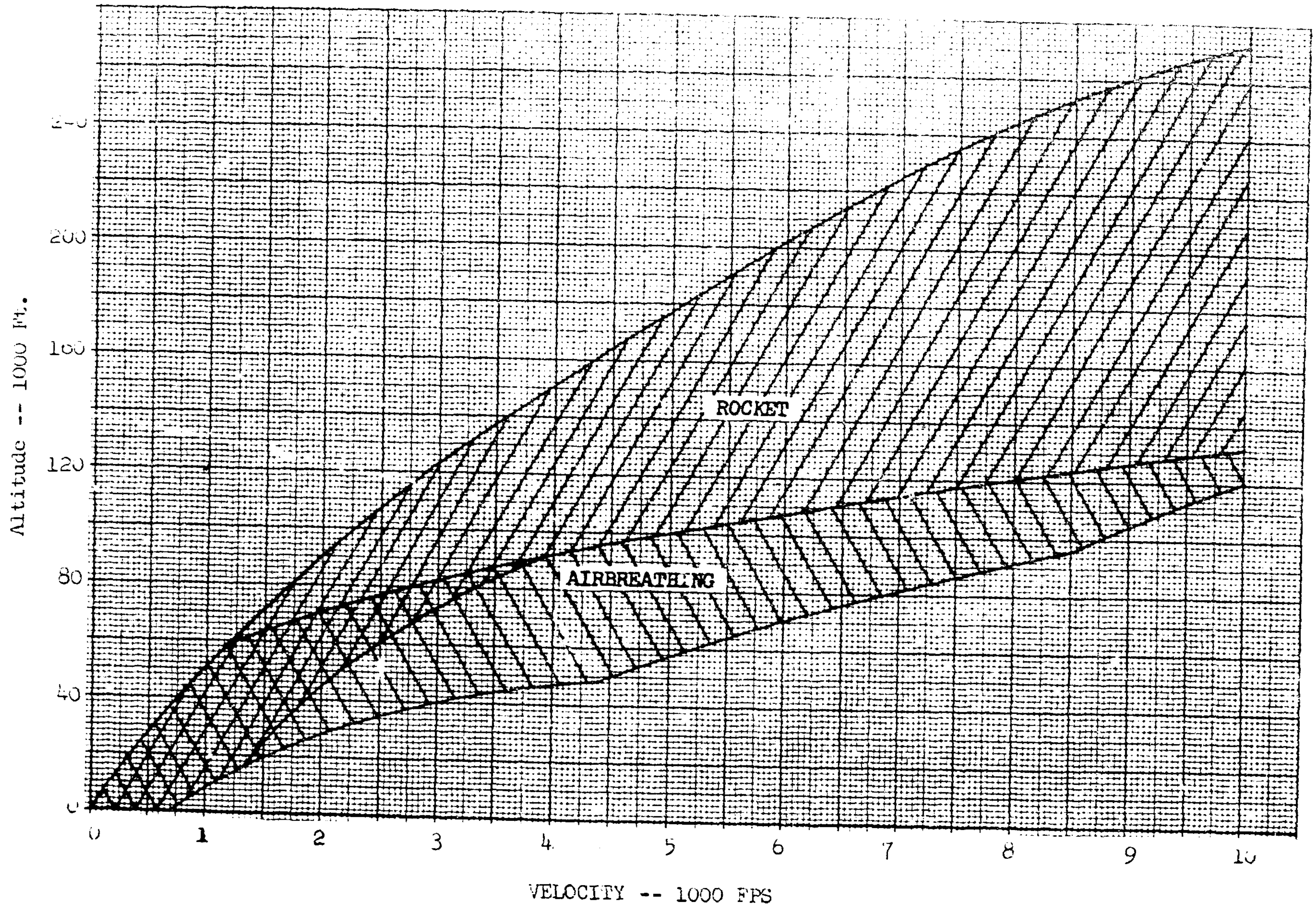

Fig. 5 Two Stage, Manned, Recoverable Launch Systems Trajectory Envelope

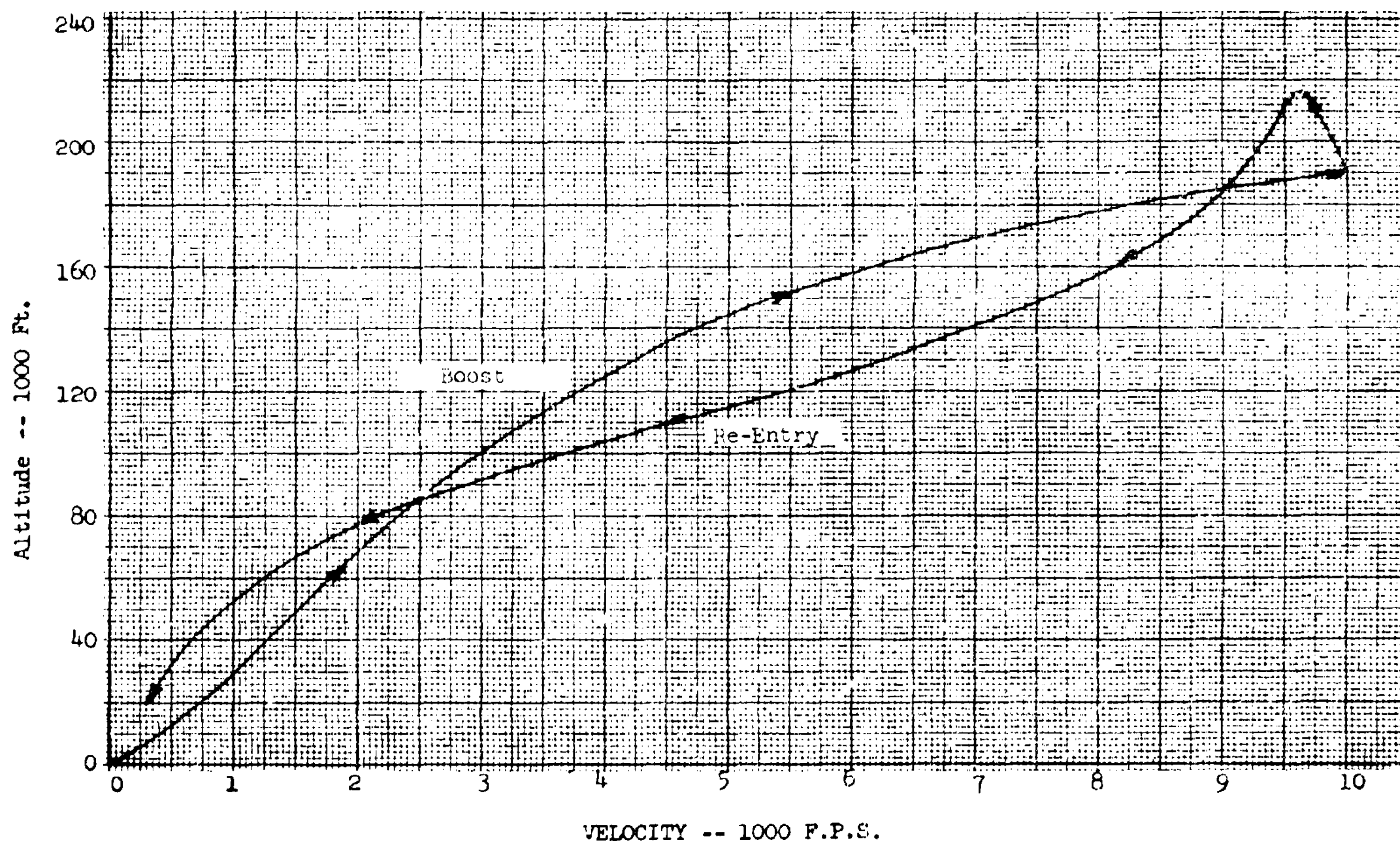

Fig. 6 Typical Boost Trajectory for 2 Stage Recoverable VTOHL Vehicle

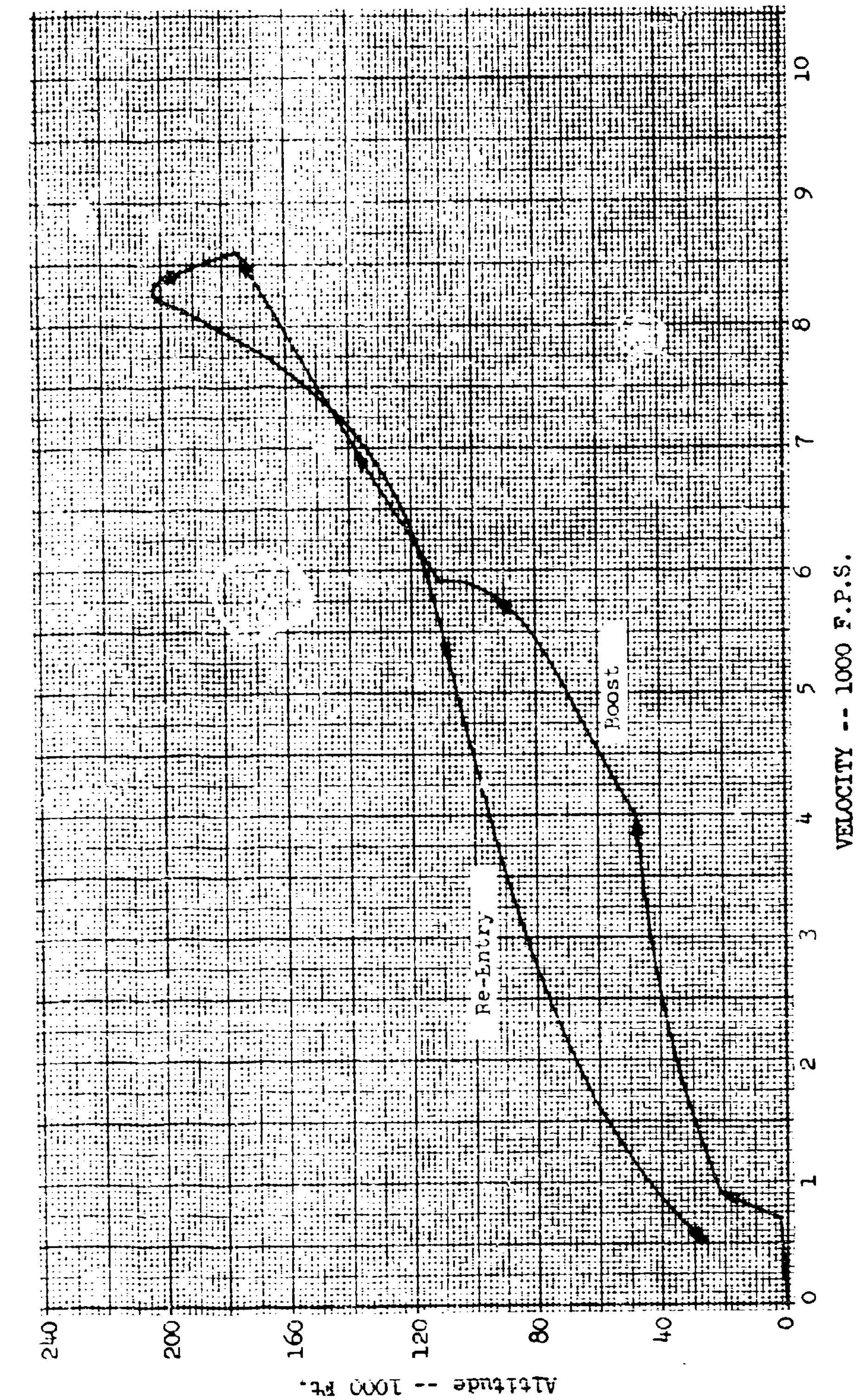

Fig. 7 Typical Boost Trajectory for 2 Stage Recoverable HTOHL Vehicle

SECTION 3

ESCAPE REQUIREMENTS AND CRITERIA

Safety of the crew of any manned aerospace vehicle is of prime importance to both the crew and the success of the program. Until such time that actual flight experience has established a high reliability for successful mission completion, a means for crew escape and recovery must be provided. The present study was concerned with the crew escape provisions for the two stage manned vehicles discussed in Section 2. The following criteria were applied to the investigation.

3.1 Each stage carries a nominal crew of 3 men. It was found, however, that the results of the study are applicable to other crew compartments containing from two to five men. For crews greater than 5 men, the size of the escape vehicle becomes prohibitive. In the same vein, escape system for passenger carrying vehicles would impose large weight and structural increases which in turn would restrict the overall capability of the vehicle, therefore the vehicle itself would be the escape system.

3.2 Crew escape techniques shall be capable of providing successful escape throughout the mission profile of both stages as presented in Section 2. This requires that any escape procedure for a two stage separated crew compartment vehicle operate both in the staged and unstaged configuration.

3.3 Escape concepts shall perform within the state-of-the-art of human tolerance limits on acceleration as set forth by Figure 8 and the limits on tumbling, temperature, vibration and radiation such as presented in Reference 5, to place the crew in a condition to accomplish action to service and aid in their location and rescue.

3.4 Crew compartment location and separation characteristics shall exist such that clearance during escape is assured for all conditions.

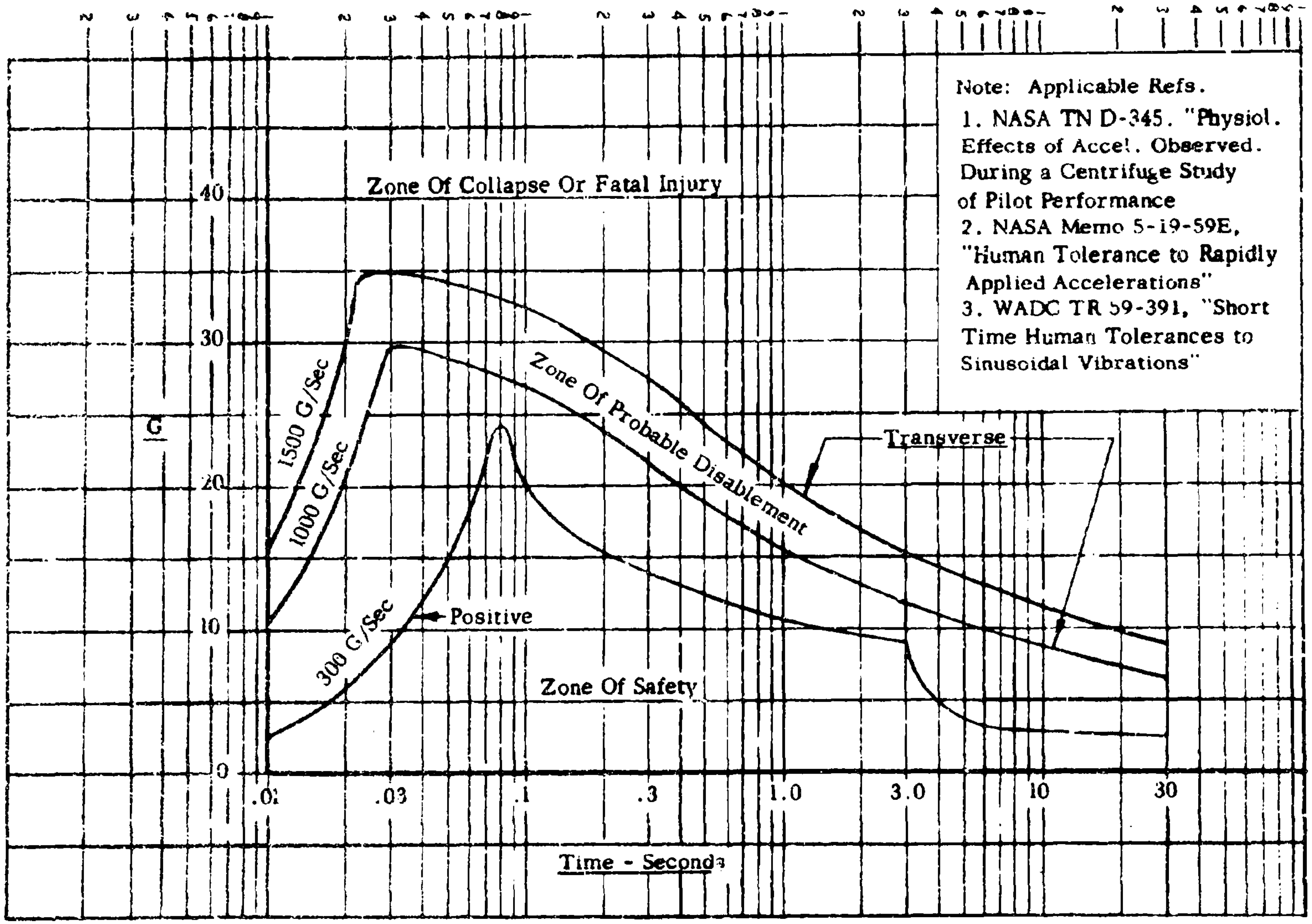

Fig. 8 Limits Of Human Tolerance

SECTION 4

HAZARDS ANALYSIS

Having assumed the requirement for escape capability, it is necessary to investigate the vehicle system and mission in order to determine those events which dictate crew escape and their location in the mission time history.

The many different emergencies which might arise during a two stage space launch boost are too numerous to mention and impossible to pre-determine. The approach taken in this study for the hazards analysis was to divide the vehicle mission profile into functional stages, and then describe and discuss the major operations which take place during a particular functional stage.

The end result of a crew protection system is to provide the highest degree of safety for all crew members without imposing too stringent restrictions on the vehicle mission. For this study, the primary objective was to determine what unique problems, if any, are present for crew escape systems on two-stage manned recoverable vehicles. This means that both stages are manned, the first stage is a sub-orbital booster and the second stage the orbital vehicle. The period in which the two stages are mated, from pre-launch and count-down until actual separation of the second stage, is covered by this study.

A general vehicle systems hazards analyses was made. The results of this investigation were combined with typical VTOHL and HTOL missions to provide tables of potential hazards for each of these vehicle classifications.

It should be noted, however, that for any specific design, it would be necessary to make a detailed hazards analysis including reliability characteristics. This would be required in order to insure reliable design and provide the information necessary for selection of escape concepts and parameters to be sensed by any malfunction detection system.

Critical escape areas have been defined on the basis of the hazards analysis. Also an investigation of explosion characteristics was made since explosions, in general, are the most severe hazard for the reasons that they have the most rapid onset time and affect a large environmental area.

4.1 VEHICLE SYSTEM HAZARDS

Hazards to crew safety in a manned aerospace vehicle can arise from either the vehicle systems or the mission events and environment. The first phase of the hazards investigation was an analysis of possible vehicle system hazards. The results are presented in Table 1 which is a summary of system hazards. The effects of a subsystem malfunction on the vehicle and the crew are described, along with possible corrective action to be taken.

4.2 VTOHL HAZARDS

A nominal mission operation for a two stage low earth orbit VTOHL recoverable vehicle was defined and examined and the following sequence was established. The two stage vehicle, consisting of a sub-orbital booster and an orbital second stage, would be launched vertically on a pre-programmed ballistic trajectory such as the trajectory shown in Figure 6. The flight path is generally controlled by internally programmed and ground command guidance systems. Studies, however, are presently being made on the possibility of piloted VTOHL boost flight. This would introduce the additional problem of manually induced hazards but it would not be

TABLE 1

HAZARDS AND EFFECTS ON OVERALL SYSTEM

System Failure Mode	System Failure Cause	Effects on Vehicle	Effects on Crew	Corrective Action
ENVIRONMENTAL CONTROL				
Temperature control inoperative	·Leak, power loss, puncture	·Electronics cooling & life support system	·Emergency situation. Use backup system	·Survey to determine if fix possible. If not, abort mission
Humidity Control inoperative	·Power Loss ·Extreme Temperature	·Affects water reclation system	·Discomfort, use backup system	·Locate and repair if possible. Possibly abort mission
Explosion of nitrogen, oxygen or CO_2 pressure containers	·Puncture ·Failure of valves ·Lines clogged	·Possible structural and/or component failure	·Emergency situation	·Shut off electrical components. Abort mission. Prepare for escape situation
Trace contaminant control inoperative	·Power loss, warning system inoperative	·Not serious	·Serious. Crew unknowingly subjected to toxic, fire hazards	·Issue trace contaminant badges to crew and monitor regularly. Abort mission if not repairable
Equipment cooling (air and/or liquid) system inoperative	·Power loss ·Leak ·Puncture ·Vibration	·Reduces output of communications and life support system. Potential fire hazard	·Not immediately serious	·Attempt to locate and repair. If not possible, abort mission.
LIFE SUPPORT				
Contamination of feeding system	·Moisture, puncture, extreme temperature	·None	·Minor to serious. Could result in illness or death	·Locate contamination source and repair. Abort mission if repair impossible.
Contamination of water and/or water reclamation system	·Puncture, bad filters	·None	·Minor to serious. Could result in illness	"
Inoperative water reclamation, waste management or hygiene system	·Extreme temperature ·Loss of power ·Component failure	·None	·Minor if second stage not in orbit	"
STABILIZATION AND CONTROL				

lamation, waste management or hygiene system	· Loss of power · Component failure		not in orbit	
STABILIZATION AND CONTROL				
VTO guidance package malfunction	· Power failure	· Violent pitch over	· Subjected to high 'g' loads	· Immediate escape
Stabilization system failure	· Actuator failure · Power failure · Reaction control propellant tank failure	· Loss of control	· Disorientation · Loss of consciousness	· Immediate escape
Runaway controls	· Failure of control valve · Loss of hydraulic pressure	· Minor to serious · Possibly could be trimmed out · Could cause violent maneuver	· Minor to serious · Must prepare for escape	· Abort mission · Possibly initiate crew escape
COMMUNICATIONS				
Total loss of communications	· Electrical fire requiring complete shutdown of equipment · Power failure	· Reduces or eliminates mission effectiveness	· No means of communications	· Switch to emergency batteries. Abort mission
Partial loss of communications	· Component malfunction · Battery failure · Generator system failure	· Reduces mission effectiveness	· Partial means of communications · Reduces communications output	· Attempt to locate malfunction and repair. · Abort mission if not repairable.
PROPULSION				
Propellant tank leakage	· Tank deterioration	· Extreme fire hazard	· Minor to serious · Must be alert to potential danger	· Abort mission · Prepare to escape
Propellant line rupture	· Excessive line pressure	· Loss of thrust · Erratic burning	· Serious · Highly probable to escape	"
Rocket engine explosion	· Propellant fire · Excessive pressure · Fuel rich burn	· Minor to major · Loss of control · Reduction in thruct · Possible structural failure	"	"

2

TABLE 1 (CONT'D)

HAZARDS AND EFFECTS ON OVERALL SYSTEM

System Failure Mode	System Failure Cause	Effects on Vehicle	Effects on Crew	Corrective Action
PROPULSION (CONT'D)				
Air Collection System Failure	· Component Failure · Collapsed inlets · Power failure	· No oxidizer · Loss on thrust · Inability to orbit second stage	· Minor · Second Stage Crew must decide to stay or escape	· Abort mission · Prepare to escape
GUIDANCE & NAVIGATION				
Fire in platform electronics	· Short circuit or loss of circuit breaker	· Minor to serious · If uncontrollable could cause destruction of vehicle	· Minor to serious · Must escape if fire cannot be extinguished	· Locate and attempt to extinguish · Abort mission · Prepare to escape
Malfunction of guidance computers	· Short circuit · Loss of power	· False commands to propulsion system · Overload airframe structure	· Minor to serious	· Attempt to repair · Abort mission · Prepare to escape
Complete failure of Astro platform	· Power failure · Short circuit · Fire · Gyro failure	· Minor to serious · If uncontrollable could cause destruction of vehicle · Overload airframe structure	"	"
STRUCTURES				
Material deterioration	· Corrosion	· Propellant leakage · Loss of pressurization · High fire hazard	· Pressure suits required	· Abort mission · Prepare for possible escape
Major structure failure	· Overloading (high 'g' and/or 'q's) · Material deterioration · Propellant explosion	· Loss of control	· Escape imperative	· Use escape system
ELECTRICAL POWER				
Complete loss of electrical power	· Fire · Explosion · [illegible]	· Loss of Communication · All electrical subsystems inopera-	· Loss of Communication	· Abort Mission · Use emergency power · Attempt to locate

	· Fire · Gyro failure	could cause destruction of vehicle · Overload airframe structure		
STRUCTURES				
Material deterioration	· Corrosion	· Propellant leakage · Loss of pressurization · High fire hazard	· Pressure suits required	· Abort mission · Prepare for possible escape
Major structure failure	· Overloading (high 'g' and/or 'q's) · Material deterioration · Propellant explosion	· Loss of control	· Escape imperative	· Use escape system
ELECTRICAL POWER				
Complete loss of electrical power	· Fire · Explosion · Cable disconnect	· Loss of Communication · All electrical subsystems inoperative · Loss of instruments	· Loss of Communication	· Abort Mission · Use emergency power · Attempt to locate source and repair · Prepare to escape
ARMAMENT				
Explosion of stored weapons	· Personnel error · Fire · Stray signal	· Fire or catastrophic	· Serious emergency	· Jettison weapons · Abort mission · Initiate crew escape
Enemy action	· Missile attack · Nuclear explosion	· Destruction · Serious damage	· Serious emergency · Radiation	· Evasive action · Anti-missile defense · Abort mission · Crew escape
CREW				
Inability to perform assigned tasks	· Sickness · Enemy action	· If task can be performed by crew member at different station, the effects are minor	· Added tasks to remaining crew members	· Depending upon seriousness of ailment, mission is either carried out or aborted.

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peculiar or unique to two staged manned systems.

Upon reaching the required velocity and altitude, the staging maneuver is accomplished by first shutting down the booster engines and then igniting the second stage propulsion system. The elapsed time from lift-off to staging is approximately 3-1/2 to 4 minutes, for staging velocities in the 8000 to 10,000 fps range. The propulsion system used during the boost phase consists of the liquid rockets in the boost section and possibly solid booster motors during the lift-off phase, which are jettisoned after burnout. The use of solid rockets as the primary propulsion system would merely affect the characteristics of propulsion and propellant system failures but not eliminate them.

4.2.1 SEQUENCE OF EVENTS. Table 2 outlines a typical operating mode for a recoverable VTOHL vehicle.

TABLE 2

TYPICAL VTOHL SEQUENCE OF EVENTS

EVENT	DESCRIPTION	TIME DURATION
Prelaunch	• Final phase of countdown • Crews Board Vehicle • Propellant Loading	Approximately 1 Hour
Launch	• Engine Ignition thru Lift-off • Azimuth Roll Correction • Pitch Over	Approximately 30 Seconds
Ballistic Trajectory	• Accelerate thru Maximum Dynamic Pressure to Required Staging Velocity	Approximately 3 Minutes
Staging	• Booster Engine Cut-off • 2nd Stage Engine Ignition • Mechanical and/or Ballistic Release of 2nd Stage	

The sequence of events given in Table 2 can be further subdivided into the following functional stages:

Pre-Launch
- Countdown
- Crew boarding
- Propellant loading
- Hold-time

Launch
- Engine ignition
- Hold down
- Lift-off
- Azimuth roll
- Pitch over

Boost
- Acceleration
- Maximum dynamic pressure

Staging
- 1st stage engine shutdown
- 2nd stage engine ignition
- 2nd stage separation

4.2.1.1 Pre-Launch. During the final phases of the countdown the two crews board. A pre-flight check is made by the crew, and then the final stages of the countdown are completed. This includes the final propellant loading process for both stages which can be classed as a hazardous condition.

4.2.1.2 Launch. At T-0 seconds in the countdown procedure the booster engines are ignited. A delay action is built into the launch operation to allow the engines to attain maximum thrust for lift-off. During this thrust build up time, which is approximately two seconds, the launcher mechanism is in a hold position. By terminating the booster engines, this allows recovery of the entire launch configuration in the event sufficient thrust is not attained to perform lift off. The commitment to flight is made the instant the launcher hold-down mechanism is released. This is a critical point since any propulsion system malfunction could lead to the vehicle tipping over on the launch pad. Following lift-off the vehicle is automatically programmed to perform a roll maneuver to place the vehicle in the proper azimuth plane. Immediately following this, a planned pitchover occurs to put the vehicle in its programmed ballistic trajectory. The entire launch operation has been performed automatically to this point and will continue to be so until the staging maneuver. Any malfunction of the programmed trajectory will result in aborting the mission. The point at which a malfunction occurs, the severity of the malfunction, and the design characteristics of the vehicle will determine whether or not the crew will eject from the vehicle, or attempt to jettison the second stage and recover one or both stages by horizontal landings.

4.2.1.3 Boost. The pitch and roll maneuvers to the desired trajectory are generally completed approximately 30 seconds after lift-off. The vehicle then continues accelerating along the desired trajectory until the staging point is reached. In this phase of the flight the vehicle passes through the maximum dynamic pressure region. This is a hazardous region since the air loads on the vehicle are at their maximum and the escape concept requires large separation forces.

4.2.1.4 Staging. The elapsed time for the launch vehicle to reach the required altitude and velocity for staging is approximately 3-1/2 minutes from lift-off. The staging sequence analyzed was to first shut down the first stage engines, then ignite the second stage engines and release the second stage at a pre-determined thrust level. The critical point in this operation is the ignition of the second stage engines and the mechanical release of the second stage upon thrust buildup. Upon the successful separation of the second stage vehicle the first stage flies to a landing site. This flight can be a pure glide or a combination of glide plus powered cruise and landing. The second stage goes on into orbit and eventually returns. After

successful stage separation the results of previous one crew compartment vehicle escape studies apply.

4.2.2 VTOHL HAZARDS. Table 3 presents the results of a hazards analysis for a typical VTOHL vehicle. This information was prepared by combining the functional hazards and mission stages described above. It shows the major malfunctions which would be most likely to occur during a particular phase of the mission profile.

In describing a particular malfunction it is impossible to know the severity of the situation until it actually occurs, therefore many of the cases noted call for the crew to prepare for possible escape. Most any one of these situations could degenerate to "escape imperative", if the malfunction was severe enough. The conclusion drawn from this analysis is that crew protection systems are necessary throughout the entire operating mode of the vehicle.

4.3 HTOL HAZARDS

A nominal mission operation for a two-stage low earth orbit HTOL recoverable vehicle was defined and examined and the following flight sequence was established. The HTOL vehicle will take-off from a conventional runway or lift off from a sled carriage under manual control by the crew. The vehicle will then fly a conventional lifting trajectory up to some high supersonic Mach number. From this point a ballistic rocket trajectory would be flown to the desired staging point. A typical HTOL trajectory has been presented in Figure 7. Manual control by the crew is anticipated for most of the flight. This nominal mission would use air breathing propulsion up to the start of the rocket trajectory. The elapsed time from take-off to staging would be approximately fifteen minutes.

As indicated in the mission definition description in Section 2.2, there are numerous types of HTOL vehicles, e.g. rocket propulsion in both stages or the use of air collection. The flight characteristics of each of these systems would be somewhat different in the aspects of trajectory and flight time. These differences would have some affect on a detailed hazards analysis but a negligible effect on a generalized hazards analysis such as presented herein. Also, these differences should have no unique effects on two stage manned vehicles.

4.3.1 SEQUENCE OF EVENTS. Table 4 outlines a typical sequence of operating modes for an HTOL vehicle without the air collection operation. The air collection mode would increase the time in the supersonic Mach range.

The sequence of events given in Table 4 can be further subdivided into the functional stages listed below. It should be noted that in several areas, especially pre-takeoff and staging, the functional stages for the HTOL are identical with those of the VTOHL discussed in Section 4.2.

Pre-Takeoff
- Crew Boarding
- Propellant Loading
- Engine Start
- Taxi & Run-up
- Ground Roll

Take-Off
- Lift off
- Initial Pullup

Table 3 - VTOHL Hazards

● MANDATORY ESCAPE (BOTH STAGES)

◑ MANDATORY ESCAPE-2ND STG. (1ST STG. ALERT)

◎ ABORT MISSION-BOTH STG'S. ALERT FOR POSSIBLE ESCAPE

○ HAZARD REQ. ABORT ONLY

□ HAZARD NOT APPLICABLE TO THIS PHASE OF MISSION

		PROPULSION SYSTEM														STRUC		GUIDANCE & CONTR.			STAGING		
		LIQUIDS							SOLIDS					AIR									
MISSION PHASE		FIRE/EXPLOSION	LEAKAGE	NO START	SYS. FAIL. REQ. DETANKING	EARLY SHUTDOWN	NO SHUT DOWN	MAX. THRUST NOT ATTAINED	PRE-IGNITION	FAILURE TO IGNITE	ERRATIC BURN	EARLY BURNOUT	FAILURE TO JETTISON	TURBO-JET NO START	TURBO-JET FLAMEOUT	MAJOR STRUC. FAILURE	MATERIAL DETERIORATION	FAILURE TO ROLL	FAILURE TO PITCH OVER	RUNAWAY MANUAL CONTROLS	NO SEPARATION	DAMAGE DURING SEPARATION	NO 2ND STG. ROCKETS IGN.
PRE-LAUNCH	COUNTDOWN	○	○	□	○	□	□	□	○	□	□	□	□	□	□	○	○	□	□	□	□	□	□
	CREW BOARDING	●	◎	□	○	□	□	□	●	□	□	□	□	□	□	●	◎	□	□	□	□	□	□
	PROPELLANT LOAD.	●	◎	□	◎	□	□	□	●	□	□	□	□	□	□	●	◎	□	□	□	□	□	□
	HOLD TIME	●	◎	□	◎	□	□	□	●	□	□	□	□	□	□	●	◎	□	□	□	□	□	□
LAUNCH	ENGINE IGNITION	●	◎	◎	◎	◎	□	○	□	◎	◎	◎	□	□	□	●	◎	□	□	○	□	□	□
	HOLD-DOWN	●	◎	◎	◎	◎	□	○	□	◎	◎	◎	□	□	□	●	◎	□	□	○	□	□	□
	LIFT-OFF	●	◎	□	●	●	□	◎	□	●	●	●	□	□	□	●	◎	□	□	●	□	□	□
	AZIMUTH ROLL	●	◎	□	□	●	□	◎	□	□	◎	●	□	□	□	●	◎	◎	□	●	□	□	□
	PITCH-OVER	●	◎	□	□	●	□	◎	□	□	◎	●	□	□	□	●	◎	◎	◑	●	□	□	□
BOOST	ACCELERATION	●	◎	□	□	◎	□	◎	□	□	◎	◎	●	□	□	●	◎	◎	●	●	□	□	□
	MAX.DYN. PRESSURE	●	◎	□	□	◎	□	◎	□	□	◎	◎	●	□	□	●	◎	◎	●	●	□	□	□
STAGING	1ST STAGE SHUTDOWN	●	◎	□	□	◎	◎	◎	□	□	□	□	□	□	□	●	◎	◎	◎	◎	□	□	□
	2ND STAGE IGNITION	●	◎	◎	□	◎	◎	◎	□	□	□	□	□	□	□	●	◎	◎	◎	◎	●	◎	◎
	2ND STG. SEPARATION	●	◎	□	□	◎	◎	◎	□	□	□	□	□	□	□	●	◎	◎	◎	◎	◑	◎	◎
RE-ENTRY	INITIAL RE-ENTRY	●	◎	□	□	□	◎	◎	□	□	□	□	□	□	□	●	◎	◎	□	●	◎	□	□
	PULL-UP	●	◎	□	□	□	◎	◎	□	□	□	□	□	□	□	●	◎	◎	□	●	◎	□	□
	GLIDE	●	◎	□	□	□	◎	◎	□	□	□	□	□	□	□	●	◎	◎	□	◎	◎	□	□
	DECEL. TO CRUISE	●	◎	□	□	□	◎	◎	□	□	□	□	□	□	□	●	◎	◎	□	◎	◎	□	□
CRUISE	POWERED CRUISE	●	◎	□	□	□	◎	◎	□	□	□	□	□	●	◎	●	◎	◎	□	◎	◎	□	□
LANDING	APPROACH	●	◎	□	□	□	◎	◎	□	□	□	□	□	□	●	●	◎	◎	□	●	◎	□	□
	TOUCHDOWN	●	◎	□	□	□	◎	□	□	□	□	□	□	□	□	●	◎	□	□	○	◎	□	□
	ROLLOUT	●	◎	□	□	□	◎	□	□	□	□	□	□	□	□	●	◎	□	□	○	□	□	□
	TAXI	●	◎	□	□	□	◎	□	□	□	□	□	□	□	□	●	◎	□	□	○	□	□	□
	DISEMBARK	●	□	□	□	□	□	□	□	□	□	□	□	□	□	●	◎	□	□	□	□	□	□

3 - VTOHL Hazards Table

STRUC	GUIDANCE & CONTR.			STAGING			CREW			HYDRAULIC & PNEU.				ELEC	COMM. & NAV.			INSTRUMENT.			ENVIRON.				ARMAMENT	
MATERIAL DETERIORATION	FAILURE TO ROLL	FAILURE TO PITCH OVER	RUNAWAY MANUAL CONTROLS	NO SEPARATION	DAMAGE DURING SEPARATION	NO 2ND STG. ROCKETS IGN.	SICKNESS	PHYSICAL HANDICAP	PSYCHOLOGICAL HAZARD	LOSS OF TANK PRESSURE	OVER PRESSURIZATION	LOSS OF PRESS. TO SUB-SYS.	ACTUATOR FAILURE	ELECTRICAL POWER FAILURE	LOSS COMM. BETWEEN STAGES	LOSS COMM. WITH GROUND	FAILURE NAVIGATIONAL EQUIP.	LOSS FLIGHT INSTR.	LOSS PROPULSION INSTR.	LOSS ENVIRONMENTAL INSTR.	TEMP. CONTROL SYS. FAILURE	OXYGEN SYSTEM FAILURE	LOSS OF CABIN PRESSURE	CO_2/H_2O SYS. FAILURE	ENEMY ATTACK	EXPLOSION OF STORED WEAPONS
○	□	□	□	□	□	□	○	○	○	○	○	○	○	○	○	□	□	○	○	○	○	○	○	○	○	○
◉	□	□	□	□	□	□	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
◉	□	□	□	□	□	□	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
◉	□	□	□	□	□	□	○	○	○	◉	◉	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
◉	□	□	○	□	□	□	○	◉	◉	●	●	●	◉	◉	○	○	◉	◉	●	○	○	○	○	◉	◉	●
◉	□	□	○	□	□	□	○	◉	◉	●	●	●	◉	◉	○	○	◉	◉	●	○	○	○	○	◉	◉	●
◉	□	□	●	□	□	□	○	◉	◉	●	●	●	◉	◉	○	○	◉	◉	●	○	○	○	○	◉	◉	●
◉	◉	□	●	□	□	□	○	◉	◉	●	●	●	◉	◉	○	○	◉	◉	●	○	○	○	○	◉	◉	●
◉	◉	◐	●	□	□	□	○	◉	◉	●	●	●	◉	◉	○	○	◉	◉	●	○	○	○	○	◉	◉	●
◉	◉	●	●	□	□	□	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	○	○	○	○	◉	◉	●
◉	◉	●	●	□	□	□	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	◉	□	□	□	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	◉	●	◉	◉	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	◉	◐	◉	◉	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	□	●	◉	□	□	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	□	●	◉	□	□	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	□	◉	◉	□	□	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	□	◉	◉	□	□	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	□	◉	◉	□	□	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	○	○	○	○	□	◉	●
◉	◉	□	●	◉	□	□	□	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	□	□	□	□	□	◉	●
◉	□	□	○	◉	□	□	□	□	□	◉	◉	◉	◉	◉	○	○	◉	◉	◉	□	□	□	□	□	◉	●
◉	□	□	○	□	□	□	□	□	□	◉	◉	◉	◉	◉	○	○	◉	◉	◉	□	□	□	□	□	◉	●
◉	□	□	○	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	◉	●
◉	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	◉	●

1ST & 2ND STAGES MATED IN NORMAL FLIGHT CONFIGURATION

ASSUMING THE 1ST & 2ND STAGES REMAIN MATED UNDER AN EMERGENCY CONDITION. (FOR A TANDEM STAGED VTOHL VEHICLE IT IS HIGHLY IMPROBABLE THAT THE 2 STAGE WOULD REMAIN JOINED AND LAND.)

2

Subsonic Ascent
- Rocket or turbojet acceleration
- Lifting trajectory

Supersonic Ascent
- Rocket, turboramjet or ramjet acceleration
- Lifting trajectory
- Maximum dynamic pressure

Hypersonic Ascent
- Rocket or rocket-ramjet overlap acceleration
- Ballistic trajectory

Staging
- 1st Stage engine shutdown
- 2nd Stage engine ignition
- 2nd Stage separation

TABLE 4

TYPICAL HTOL OPERATING MODES

Event	Description	Time Duration
Pre-Takeoff	• Crews Board Vehicle • Final Pre-Flight Check • Propellant Loading • Engine Start • Ground Roll	Approximately 30 Minutes
Take-Off	• Lift-Off • Initial Pull-up	Approximately 30 seconds
Subsonic Ascent	• Lifting Trajectory • Rocket or Turbojet Acceleration	Approximately 30 seconds
Supersonic Ascent	• Lifting Trajectory • Rocket-Turboramjet Acceleration • Maximum Dynamic Pressure	Approximately 2 minutes
Hypersonic Ascent	• Rocket or Rocket/Turboramjet • Ballistic Trajectory	Approximately 1 Minute
Staging	• 1st Stage Engine Cutoff • 2nd Stage Engine Ignition • Mechanical and/or ballistic release of 2nd stage	Approximately 30 seconds

4.3.1.1 Pre-Takeoff. During the final phases of the countdown and just prior to propellant loading, the two crews board the vehicle. Following a complete cockpit pre-flight the propellant loading operation is accomplished. The propellant loading and engine start phases are critical since the vehicle now presents an explosion hazard.

A rocket powered HTOL would immediately initiate its ground roll follow propellant loading. An airbreathing vehicle might require a taxiing and engine runup phase prior to ground roll. System failure during the ground roll becomes most critical when the vehicle is committed to flight due to lack of sufficient runway length to stop. The crew escape system must be capable of successfully recovering the crew in the event of a catastrophic failure during this phase.

4.3.1.2 Liftoff. At liftoff the vehicle retracts its gear, and performs a pull-up maneuver. This is a hazardous condition since the vehicle is generally operating at maximum power close to the ground.

4.3.1.3 Subsonic Ascent. After takeoff the vehicle climbs and accelerates to the altitude at which it will accelerate to supersonic speeds. In this phase the external environmental conditions are not severe but the vehicle system hazards still exist.

4.3.1.4 Supersonic Ascent. The vehicle accelerates to supersonic speeds and continues accelerating to some high supersonic Mach number. Due to the nature of orbital missions the vehicle would be flying a pre-selected trajectory. Since manual control is envisioned there is the added problem of manually induced hazards, e.g. departure from the specified trajectory in a critical region. The problem of manual induced hazards are more than offset, however, by the presence of man in the system as an active participant. These aspects of manual flight apply also in the other functional mission stages.

During the supersonic ascent phase the maximum dynamic pressure is encountered. This imposes the greatest loads on the vehicle and the maximum requirements on the separation forces.

4.3.1.5 Hypersonic Ascent. Two stage vehicles having staging points in the velocity range greater than approximately 6000 ft/sec. will require a rocket phase. This flight region encounters severe aerodynamic heating effects. It also introduces the hazard of propulsion mode switchover. This can be accomplished as a simultaneous switchover or with a period of airbreathing and rocket overlap.

4.3.1.6 Staging. The staging sequence involves shutting down the first stage propulsion system, igniting the second stage engines and releasing the cond stage. Staging maneuvers and the optimum sequencing of these operations are presently undergoing investigation. The critical aspects are second stage ignition and release from the first stage. Staging generally occurs either in a region of severe aerodynamic heating or a region from which a glide trajectory will enter a region of severe aerodynamic heating.

After staging the first stage returns and lands and the second stage goes on to orbit and eventually returns and lands. In their return phases each stage may glide or have a combination of gliding and powered flight.

4.3.2 HTOL HAZARDS. Table 5 presents the results of a hazards analysis for HTOL vehicles. This information was prepared by combining the system hazards

Table 5 HTOL Hazards Table

●	MANDATORY ESCAPE (BOTH STAGES)
◐	MANDATORY ESCAPE- 2ND STG. (1ST STG. ALERT)
◉	ABORT MISSION-BOTH STG'S. ALERT FOR POSSIBLE ESCAPE
○	HAZARD REQ. ABORT ONLY
□	HAZARD NOT APPLICABLE TO THIS PHASE OF MISSION

MISSION PHASE		PROPULSION SYSTEM								STRUC		GUIDANCE & CONTROL				FUEL SYSTEM							STAGING	
		AIR		LIQUID				SLED																
		TURBO-JET-COMPLETE FAILURE	TURBO-JET-PARTIAL FAILURE	LIQUID AIR ROCKETS-COMPL. LOSS	LIQ. AIR ROCKETS-PARTIAL LOSS	RAMJETS-COMPLETE LOSS	RAMJETS-PARTIAL LOSS	SLED BOOSTER-PARTIAL LOSS	SLED BOOSTER-COMPLETE LOSS	MAJOR STRUCTURAL FAILURE	MATERIAL DETERIORATION	ACTUATING FAILURE	STABILIZATION SYSTEM LOSS	RUNAWAY CONTROLS	AUTO-PILOT FAILURE	TANK LEAKAGE	FIRE/EXPLOSION	PLUMBING LEAKAGE	LOSS OF FULL FLOW/PRESS.	SUB-SYSTEM EQUIP. FAIL.	SYS. FAIL. REQ. DE-TANKING	SPILL OR LEAKAGE DURING TANK	FAILURE TO SEPARATE	DAMAGE DURING SEPARATION
PRE-TAKEOFF	BOARDING	□	□	□	□	□	□	□	□	◉	○	□	□	□	□	○	●	○	○	○	□	□	□	□
	PROPELLANT LOAD.	□	□	□	□	□	□	□	□	●	◉	□	□	□	□	◉	●	○	○	○	◉	◉	□	□
	ENGINE START	○	○	◉	◉	□	□	○	○	●	◉	○	□	□	□	◉	●	◉	○	○	◉	◉	□	□
	TAXI & RUN-UP	○	○	□	□	□	□	□	□	●	◉	○	□	○	□	◉	●	◉	◉	○	◉	◉	□	□
	GROUND ROLL	◉	◉	◉	◉	□	□	◉	◉	●	◉	◉	◉	◉	□	◉	●	◉	◉	◉	◉	◉	□	□
TAKEOFF	LIFT OFF	●	◉	●	◉	□	□	□	□	●	◉	●	●	●	□	◉	●	◉	●	◉	□	□	□	□
	INITIAL PULL UP	●	◉	●	◉	□	□	□	□	●	◉	●	●	●	□	◉	●	◉	●	◉	□	□	□	□
SUB-SONIC	ROCKET OR T.J.ACCEL	◉	◉	◉	◉	□	□	□	□	●	◉	●	●	●	◉	◉	●	◉	●	◉	□	□	□	□
SUPER-SONIC ASCENT	ROC.T.J.OR RJ ACCEL	◉	◉	◉	◉	◉	◉	□	□	●	◉	●	●	●	◉	◉	●	◉	●	◉	□	□	□	□
	MAXIMUM DYN. PRESS.	●	◉	●	◉	◉	◉	□	□	●	◉	●	●	●	◉	◉	●	◉	●	◉	□	□	□	□
HYPER-SONIC ASCENT	RAM-JETS	□	□	□	□	◉	◉	□	□	●	◉	◉	●	●	◉	◉	●	◉	◉	◉	□	□	□	□
	ENRICHED AIR RKT.	□	□	◉	◉	◉	◉	□	□	●	◉	◉	●	●	◉	◉	●	◉	◉	◉	□	□	□	□
STAGING	STAGING MANEUVER	□	□	◉	◉	◉	◉	□	□	●	◉	●	●	●	◉	◉	●	◉	◉	◉	□	□	◉	◉
RE-ENTRY	INITIAL RE-ENTRY	□	□	□	□	□	□	□	□	●	◉	●	●	●	◉	◉	●	◉	□	◉	□	□	◉	◉
	PULL UP	□	□	□	□	□	□	□	□	●	◉	●	●	●	◉	◉	●	◉	□	◉	□	□	◉	◉
	GLIDE	□	□	□	□	□	□	□	□	●	◉	◉	●	●	◉	◉	●	◉	□	◉	□	□	◉	◉
	DECEL. TO CRUISE	□	□	□	□	□	□	□	□	●	◉	◉	●	●	◉	◉	●	◉	◉	◉	□	□	◉	◉
CRUISE	POWERED CRUISE	◉	◉	□	□	□	□	□	□	●	◉	◉	●	●	◉	◉	●	◉	◉	◉	□	□	◉	◉
LANDING	APPROACH	●	◉	□	□	□	□	□	□	●	◉	◉	●	●	□	◉	●	◉	●	◉	□	□	◉	◉
	TOUCHDOWN	○	○	□	□	□	□	□	□	●	◉	◉	◉	◉	□	◉	●	◉	○	◉	□	□	◉	◉
	ROLL OUT	○	○	□	□	□	□	□	□	●	◉	○	○	○	□	◉	●	◉	○	◉	□	□	○	○
	TAXI	□	□	□	□	□	□	□	□	●	◉	○	□	□	□	◉	●	◉	○	◉	□	□	○	○
	DISEMBARK	□	□	□	□	□	□	□	□	●	◉	□	□	□	□	◉	●	◉	□	□	□	□	□	□

TOL Hazards Table

PLUMBING LEAKAGE	LOSS OF FUEL FLOW/PRESS.	SUB-SYSTEM EQUIP. FAIL.	SYS. FAIL. REQ. DE-TANKING	SPILL OR LEAKAGE DURING TANK	FAILURE TO SEPARATE	DAMAGE DURING SEPARATION	2ND STG. ROCKET NO LIGHT	SICKNESS	PHYSICAL HANDICAP	PSYCOLOGICAL HAZARD	LOSS OF TANK PRESSURE	OVER PRESSURE IN TANK	SUB-SYS. PRESSURE LOSS	ACTUATOR FAILURE	ELECTRICAL POWER FAILURE	LOSS COMM. BETWEEN STAGES	LOSS COMM. WITH GROUND	FAILURE NAVIGATIONAL EQUIP.	LOSS OF FLIGHT INSTR.	LOSS OF PROPULSION INSTR.	LOSS ENVIRONMENTAL INSTR.	TEMP. CONTROL SYS. FAIL.	OXYGEN SYS. FAIL	LOSS OF CABIN PRESSURE	CO_2/H_2O SYSTEM FAILURE	ENEMY ATTACK	EXPLOSION OF STORED WEAPONS
…EL SYSTEM					STAGING			CREW			HYDRAULICS & PNEU.				ELEC	COMM. & NAV.			INSTRU-MENTS			ENVIRON-MENTAL				ARMA-MENT	
○	○	○	□	□	□	□	□	○	○	○	○	○	○	○	○	○	○	□	○	○	○	○	○	○	○	○	◉
○	○	○	◉	◉	□	□	□	○	○	○	○	○	○	○	○	○	○	□	○	○	○	○	○	○	○	◉	●
◉	○	○	◉	◉	□	□	□	○	○	○	○	○	○	○	○	○	○	□	○	○	○	○	○	○	○	◉	●
◉	◉	○	◉	◉	□	□	□	○	○	○	◉	◉	○	○	○	○	○	□	○	○	○	○	○	○	○	◉	●
◉	◉	◉	◉	◉	□	□	□	○	○	○	●	●	◉	○	○	○	○	□	○	○	○	○	○	○	○	◉	●
◉	●	◉	□	□	□	□	□	○	◉	◉	●	●	◉	●	◉	○	○	□	◉	●	○	○	○	○	○	◉	●
◉	●	◉	□	□	□	□	□	○	◉	◉	●	●	◉	●	◉	○	○	○	◉	●	○	○	○	○	○	◉	●
◉	●	◉	□	□	□	□	□	○	◉	◉	●	●	◉	●	◉	○	○	○	◉	●	○	○	○	○	○	◉	●
◉	●	◉	□	□	□	□	□	○	◉	◉	●	●	◉	●	◉	○	○	○	◉	●	◉	◉	◉	◉	◉	◉	●
◉	●	◉	□	□	□	□	□	○	◉	◉	●	●	◉	●	◉	○	○	○	◉	●	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	□	□	□	□	□	○	◉	◉	◉	◉	◉	◉	◉	○	○	○	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	□	□	□	□	□	○	◉	◉	◉	◉	◉	◉	◉	○	○	○	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	□	□	◉	◉	●	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	□	◉	□	□	◉	◉	◉	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	□	◉	□	□	◉	◉	◉	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	□	◉	□	□	◉	◉	◉	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	□	□	◉	◉	◉	○	◉	◉	◉	◉	◉	◉	◉	○	○	◉	◉	◉	◉	◉	◉	◉	◉	◉	●
◉	◉	◉	□	□	◉	◉	◉	○	◉	◉	◉	◉	◉	◉	◉	○	○	○	◉	◉	○	○	○	○	□	◉	●
◉	●	◉	□	□	◉	◉	◉	□	◉	◉	◉	◉	◉	◉	◉	○	○	○	◉	◉	□	□	□	□	□	◉	●
◉	○	◉	□	□	◉	◉	◉	□	◉	◉	◉	◉	◉	◉	◉	○	○	□	○	○	□	□	□	□	□	◉	●
◉	○	◉	□	□	○	○	○	□	◉	◉	◉	◉	○	□	◉	□	□	□	○	○	□	□	□	□	□	◉	●
◉	○	◉	□	□	○	○	○	□	□	□	○	○	□	□	○	□	□	□	○	○	□	□	□	□	□	◉	●
◉	□	□	□	□	□	□	□	□	□	□	□	□	□	□	○	□	□	□	□	□	□	□	□	□	□	◉	●

1ST & 2ND STAGES MATED IN NORMAL FLIGHT CONFIGURATION

MISSION ABORTED AND VEHICLE RETURNING IN MATED CONFIGURATION

2

and mission stages discussed above. It is presented for a fictitious HTOL vehicle in that it combines several of the possible HTOL variations, e.g. rockets and airbreathing, air collection and conventional takeoff and sled assist takeoff. The information is thus more general in nature. It shows the major malfunctions which would be most likely to occur during a particular mission phase.

In describing a particular malfunction it is impossible to know the severity of the situation until it actually occurs, therefore many of the cases noted call for the crew to prepare for possible escape. Most any one of these situations could degenerate to "escape imperative", if the malfunction was severe enough. The conclusion drawn from this analysis is that crew protection systems are necessary throughout the entire operating mode of the vehicle.

4.4 CRITICAL ESCAPE AREAS

The sections above have shown that escape may be required at any point in the mission. There are, however, several regions of the mission which exert the strongest influence on the choice of escape concept and on the escape procedure. These regions can be called the critical escape areas. These critical areas which are discussed below are applicable, except as noted, not only to multi-crew compartment vehicles, but also to single crew compartment vehicles.

4.4.1 ZERO-ZERO: (VTOHL - LAUNCH PAD; HTOL - RUNWAY OR SLED). The following are the most serious difficulties which might be encountered during the early stages of aerospace vehicle launch.

1. Catastrophic explosion potential due to large quantity of propellants on board.

2. Partial or complete loss of thrust during lift-off to approximately 5000 feet altitude.

3. Loss of control during lift-off due to malfunction of flight control subsystem.

Historically, these malfunctions resulted in destruction of the vehicle soon after detection. The explosion hazard is most severe in this condition due to the greater amount of propellant and the higher, ambient pressure. The escape concept must be adequate to place each crew member at a safe distance and altitude from the exploding vehicle to safely recover the crew. This, of course, is the general requirement of an escape concept at any time and is only made more complicated at this condition by the absence of any initial velocity or altitude. As velocity and altitude increase, the severity of the escape problem decreases up to the region of high dynamic pressures.

4.4.2 MAXIMUM DYNAMIC PRESSURE. The maximum dynamic pressure area is a critical escape area since at this condition the vehicle experiences the maximum airloads and is thus most susceptible to structural failures. Also, in this region the escape concepts must overcome the largest airloads to escape from the main vehicle. Also, in achieving adequate separation from the main vehicle, the escape concept must not be put in a position such that the loads exceed human tolerance limits. There is also the problem of initial separation disturbances which at this condition have a larger effect on escape concept loading, e.g., aerodynamic interference. For these reasons the maximum dynamic pressure region exerts a strong influence on escape concept selection.

4.4.3 HIGH MACH NUMBER - HIGH ALTITUDE INCLUDING STAGING. This flight regime is

critical since it generally determines the temperature environment to which the escape concept will be exposed. For the present two stage vehicle concept the staging operation which occurs in this flight regime is very critical since during the staging operation the two stages are changing their relative positions.

4.5 EXPLOSION CHARACTERISTICS

4.5.1 GENERAL EXPLOSION CHARACTERISTICS. The most severe malfunction which might occur in any manned space launch vehicle is a catastrophic explosion of the high energy propellants. Since the hazard of explosions could influence the crew compartment location and sequencing aspects of a two staged manned aerospace vehicle with separated crew compartments, a brief investigation of explosion characteristics was made.

In order to determine the magnitude of acceleration required to place the escape capsules in a safe region from the explosion, the explosive characteristics of the propellants must be known. The standard practice in aerospace technology is to express the propellant explosion characteristics in terms of equivalent TNT explosions. Table 6 from Reference 6 presents the latest data on TNT equivalents of propellant combinations in terms of that quantity of propellant which, if involved in a detonation or explosion, produces damage equivalent to that produced by a given quantity of TNT, under similar condition. The common parameter for comparison is peak overpressure. This is empirical data and accounts for the difference in energy release and the fact that not all of the propellant releases its energy in the explosion.

The most hazardous propellant now in operational use for aerospace vehicles is liquid hydrogen-liquid oxygen. From Table 6 it is seen that 60 percent by weight of a liquid hydrogen-liquid oxygen propellant combination explodes with an equivalent TNT yield of 1 to 1. For example, the explosion potential of 1,000,000 pounds of liquid hydrogen-liquid oxygen is equivalent to 600,000 pounds of TNT.

Figures 9 and 10 show the blast pressures and arrival times of peak overpressures for one kiloton TNT explosions.

4.5.2 SCALING LAWS. Determining the overpressures and arrival times of these overpressures for explosions having TNT equivalent yield other than one (1) kiloton is accomplished by using the appropriate scaling law from Reference 7. Theoretically, a given pressure will occur at a distance from an explosion that is proportional to the cube root of the energy yield. Full scale tests have proven this relationship to be true up to the megaton range. Therefore, according to this law, if d_1 is the distance from a reference explosion of W_1 kilotons at which a certain overpressure is attained, then for any explosion of W kilotons, occurring at the same ambient pressures, these same pressures will occur at a distance d given by

$$\frac{d}{d_1} = \left(\frac{W}{W_1}\right)^{1/3}$$

The reference data in Figure 9 is based on one (1) kiloton energy yield thereby reducing the above equation to:

$$d = d_1 \quad (W)^{1/3}$$

where d_1 refers to the distance for a one (1) kiloton explosion.

TABLE 6

Liquid Propellant Explosive Equivalents

Propellant Combination	Static Test Stands	Range Launch Pads
LO_2 - LH_2	60%	60%
LO_2 - LH_2 + RP-1	Sum of (60% for LO_2-LH_2; 10% for LO_2-RP-1)	Sum of (60% for LO_2-LH_2; 20% for LO_2-RP-1)
LO_2 - RP-1 or LO_2 - NH_3	10%	20% up to 500,000 pounds plus 10% over 500,000 pounds
IRFNA - Aniline*	10%	10%
IRFNA - UDMH*	10%	10%
IRFNA - UDMH + JP-4*	10%	10%
N_2O_4 - UDMH + N_2H_4*	5%	10%
N_2O_4 - UDMH + N_2H_4 - Solid*	5% plus the explosive equivalent of the solid propellant	10% plus the explosive equivalent of the solid propellant
Tetranitromethane (alone or in combination)	100%	100%
Nitromethane (alone or in combination)	100%	100%

* These are hypergolic combinations.

Basis: Recommendations of ASESB Work Group on Explosive Equivalents for Liquid Propellants. Tetranitromethane and nitromethane are known to be detonable.

NOTES: 1. The percentage factors are used to determine the explosive equivalencies of propellant mixtures at launch pads and static test stands when such propellants are located aboveground and are unconfined except for their tankage. Any configurations other than stated above should be considered on an individual basis to determine the equivalencies.

2. The equivalencies of any non-nuclear explosives will be added to the above equivalencies.

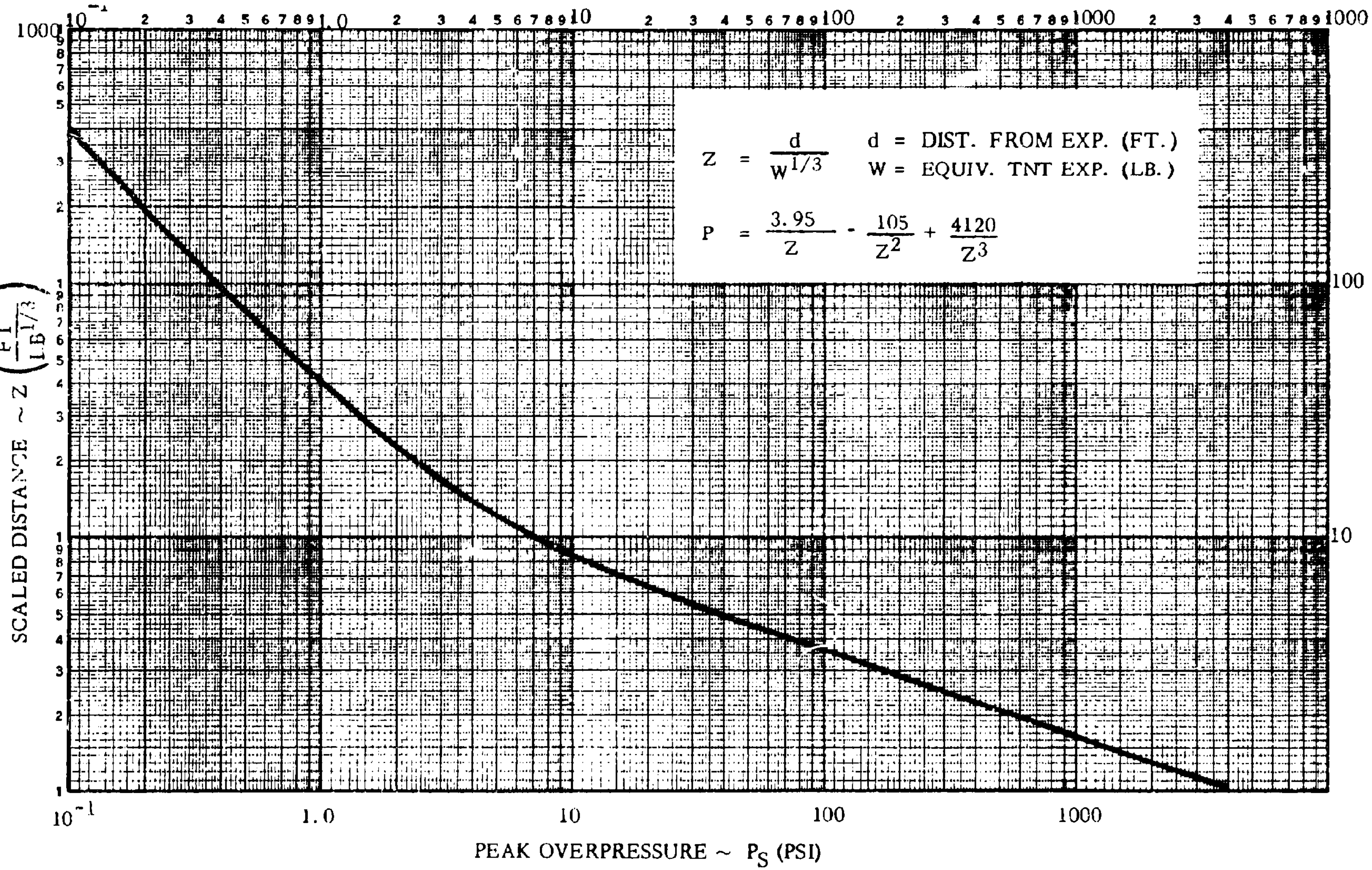


FIGURE 9 - BLAST PRESSURES FROM SURFACE AND FREE-AIR BURSTS PEAK OVERPRESSURE (P_S) VS SCALED DISTANCE (Z)

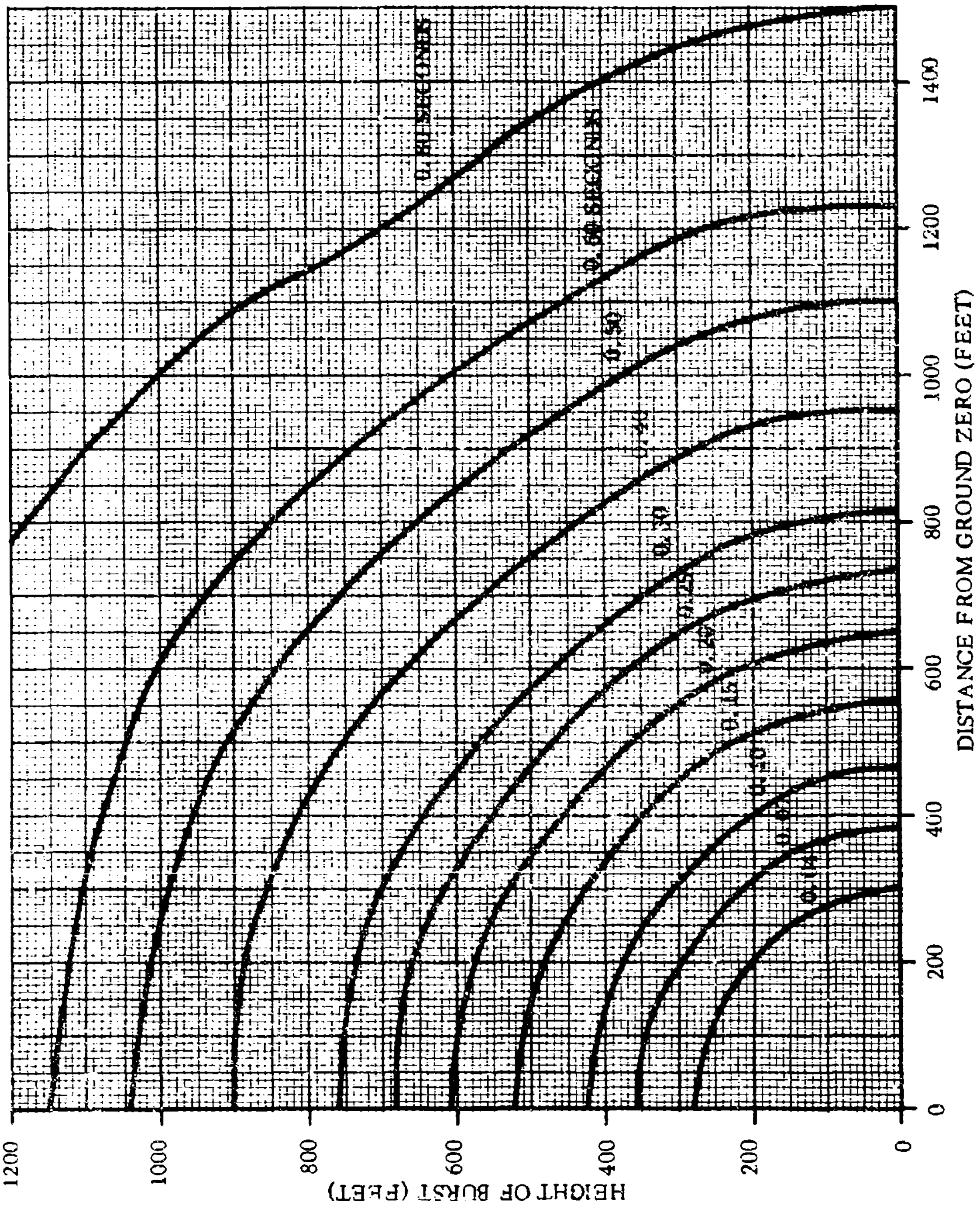


FIGURE 10 - ARRIVAL TIMES ON THE GROUND OF BLAST WAVE FOR 1-KILOTON BURST

When using Figure 9 to determine a distance d from an explosion, the term W is for the TNT equivalent in pounds. Determining time t using the data in Figure 10 for the value of time t_1, the weight W is expressed in kilotons.

$$t = t_1 \quad W^{1/3}$$

The expression for overpressure p at altitude is

$$p = p_1 \frac{P}{P_o}$$

where P is the ambient pressure at altitude, P_o is the ambient sea level pressure, and p_1 is the overpressure at sea level. The corrected value of distance for the new overpressure level is then given by

$$d = d_1 \quad W^{1/3} \left(\frac{P_o}{P} \right)^{1/3}$$

The arrival time of the overpressure at the new distance is

$$t = t_1 \quad W^{1/3} \left(\frac{P_o}{P} \right)^{1/3} \left(\frac{T_o}{T} \right)^{1/2}$$

where T_o and T are absolute ambient temperatures at sea level and altitude respectively.

For explosions up to about 5,000 feet altitude, the corrections will be small and can be omitted.

Time-distance relationships for overpressures created by various TNT equivalent explosion are shown in Figures 11 to 14 for sea level, 20, 40 and 60 thousand feet altitudes, respectively. These figures show that for an equal amount of propellant exploding at altitude, the distance a shock wave travels and the time it requires to travel that distance is shorter than that at sea level. For high energy fuel vehicles such as those used in this study, the sea level condition sets the design parameters.

A crew escape capsule designed to escape a sea level explosion will have more than adequate performance at altitude since the blast wave is weaker and the amount of propellant available for an explosion is less than at sea level.

4 5.3 EXPLOSION CONSIDERATIONS FOR ESCAPE. The primary effect of explosions affecting escape is the overpressure associated with the blast wave. The maximum value of overpressure which can be tolerated is, of course, a function of the specific escape concept design. In general, maximum values between 5 and 10 psi overpressure are used for escape concept design. As the design overpressure increases the structural weight penalty increases.

The high propagation velocity of the blast wave contributes to the severity of the explosion hazard. The magnitude of the problem is shown in Figure 15 which presents shock wave propagation characteristics in terms of time and distance for a LO_2 - LH_2 VTOHL vehicle with a propellant load having a TNT equivalent of 1 million pounds. This figure shows that the shock wave reaches an overpressure of 5 psi, 1200 feet from the point of detonation in 0.643 seconds.

These values are such that it is mandatory that the escape concept separate prior to the initial detonation. This places severe requirements on any malfunction detection system. This aspect will be explored in more detail in Section 6 on Escape Procedure.

The aspect of two crew compartments is influenced by explosion characteristics in regard to location and sequencing since one of the compartments is closer to the point of detonation.

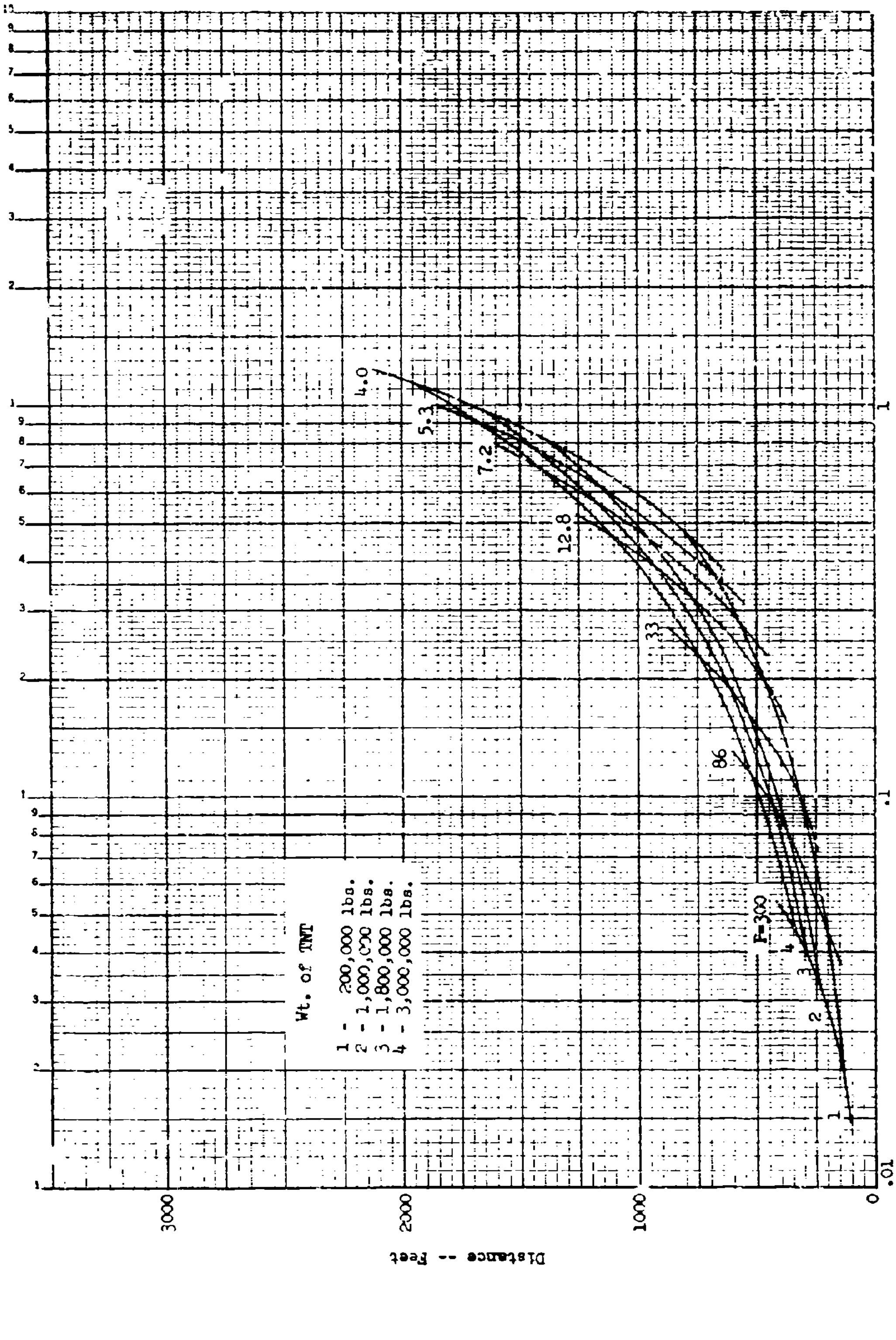


Fig. 11 Explosion Characteristics -- Sea Level

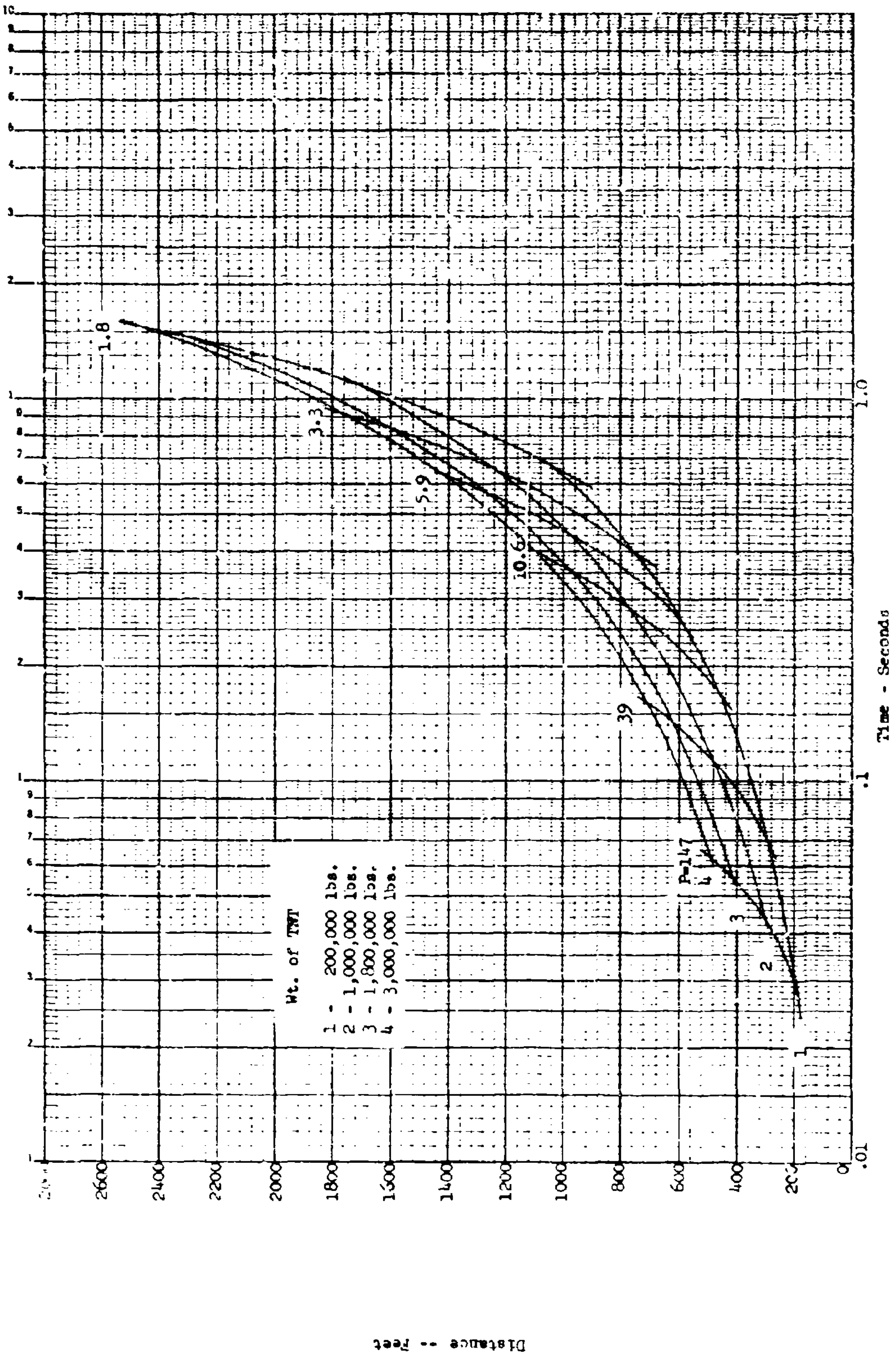


Fig. 12 Explosion Characteristics -- 20,000 Feet

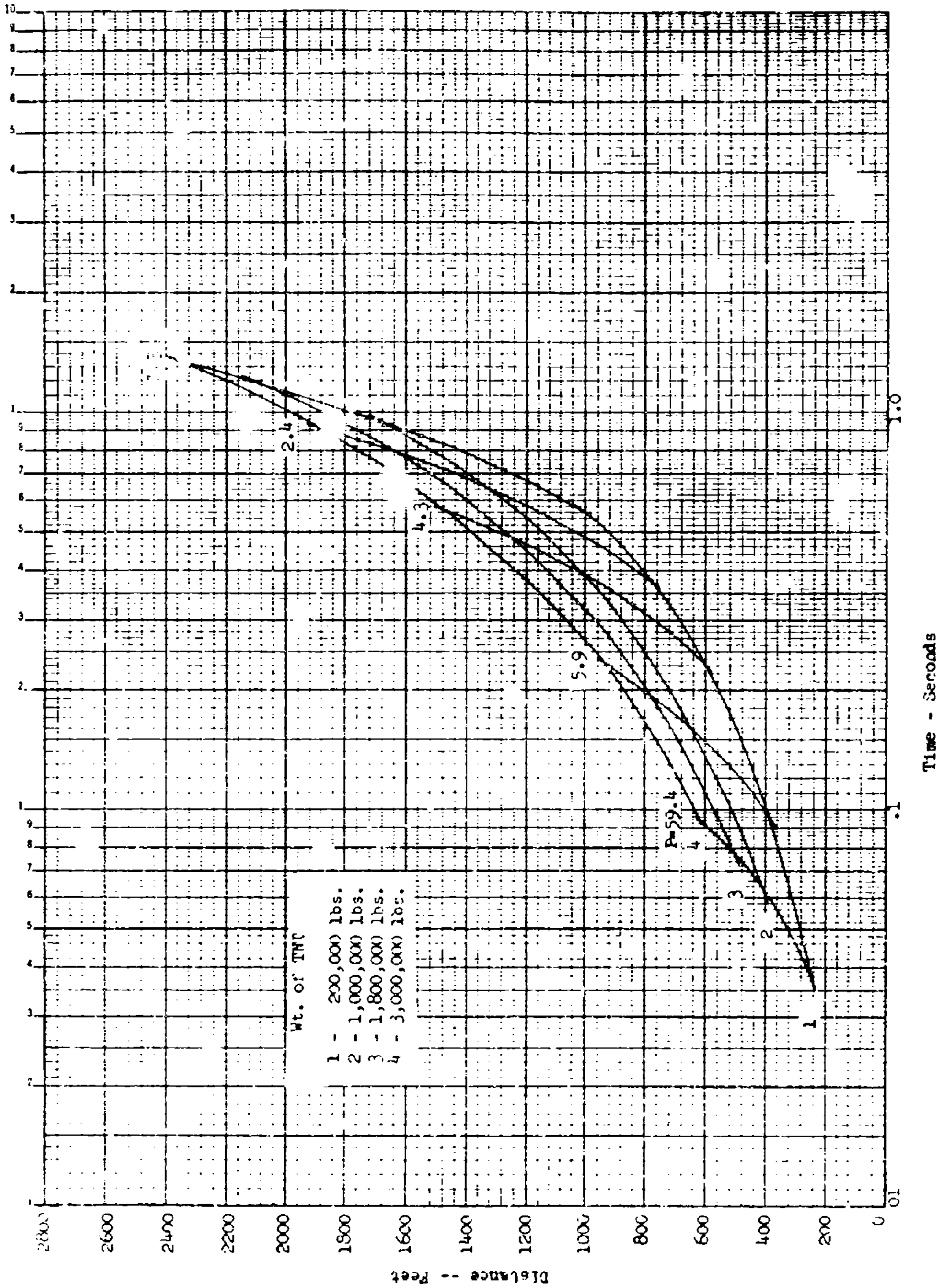


Fig. 13 Explosion Characteristics -- 40,000 Feet

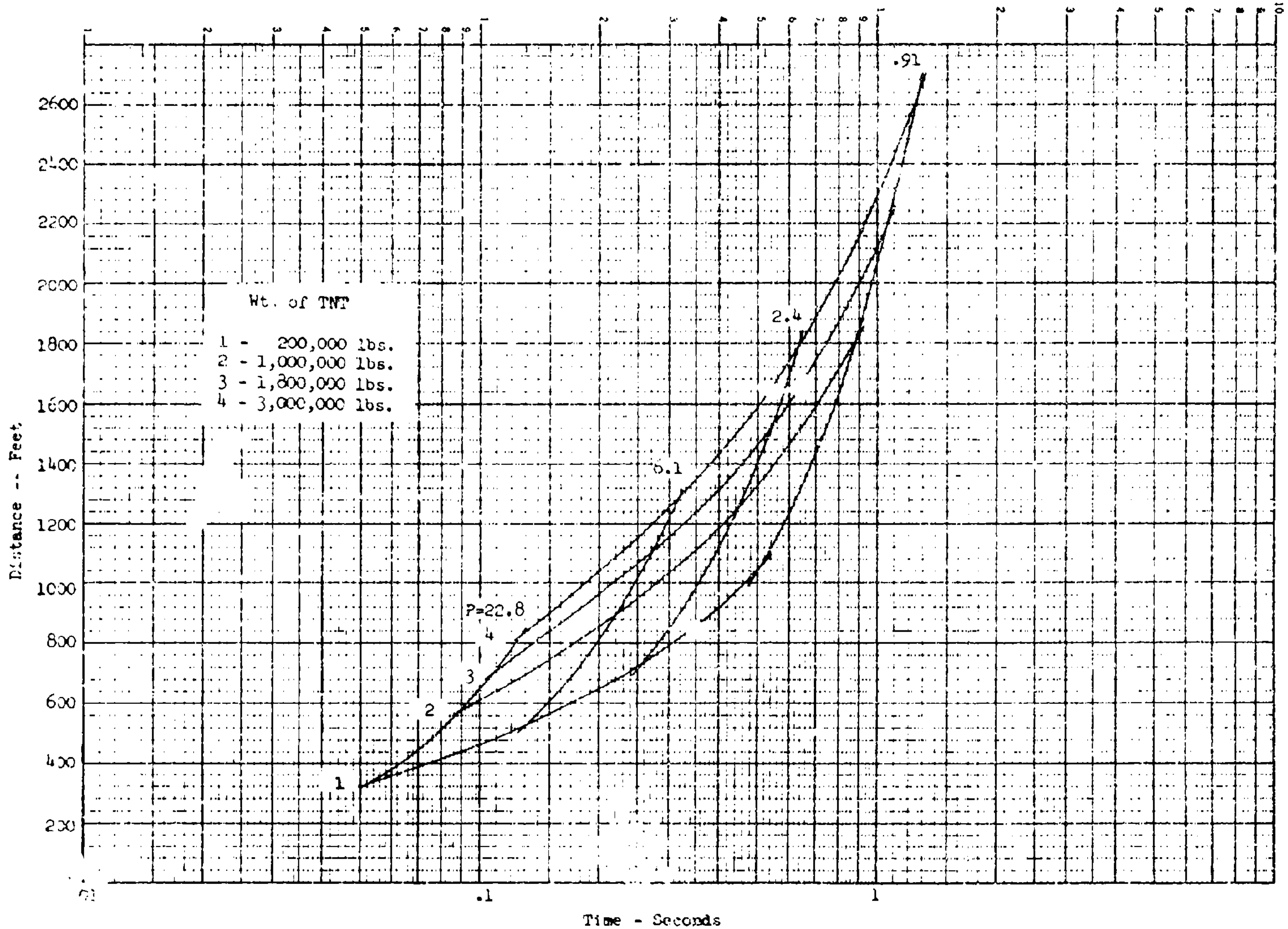


Fig. 14 Explosion Characteristics -- 60,000 Ft.

- TNT Equivalent of LO_2 - LH_2 Propellant = 1,000,000 Lbs.
- Rocket nozzle angle = 30^{o} from normal
- Maximum values - assumes complete mixing of oxidizer-fuel at 7:1 ratio.
- Sea Level Conditions

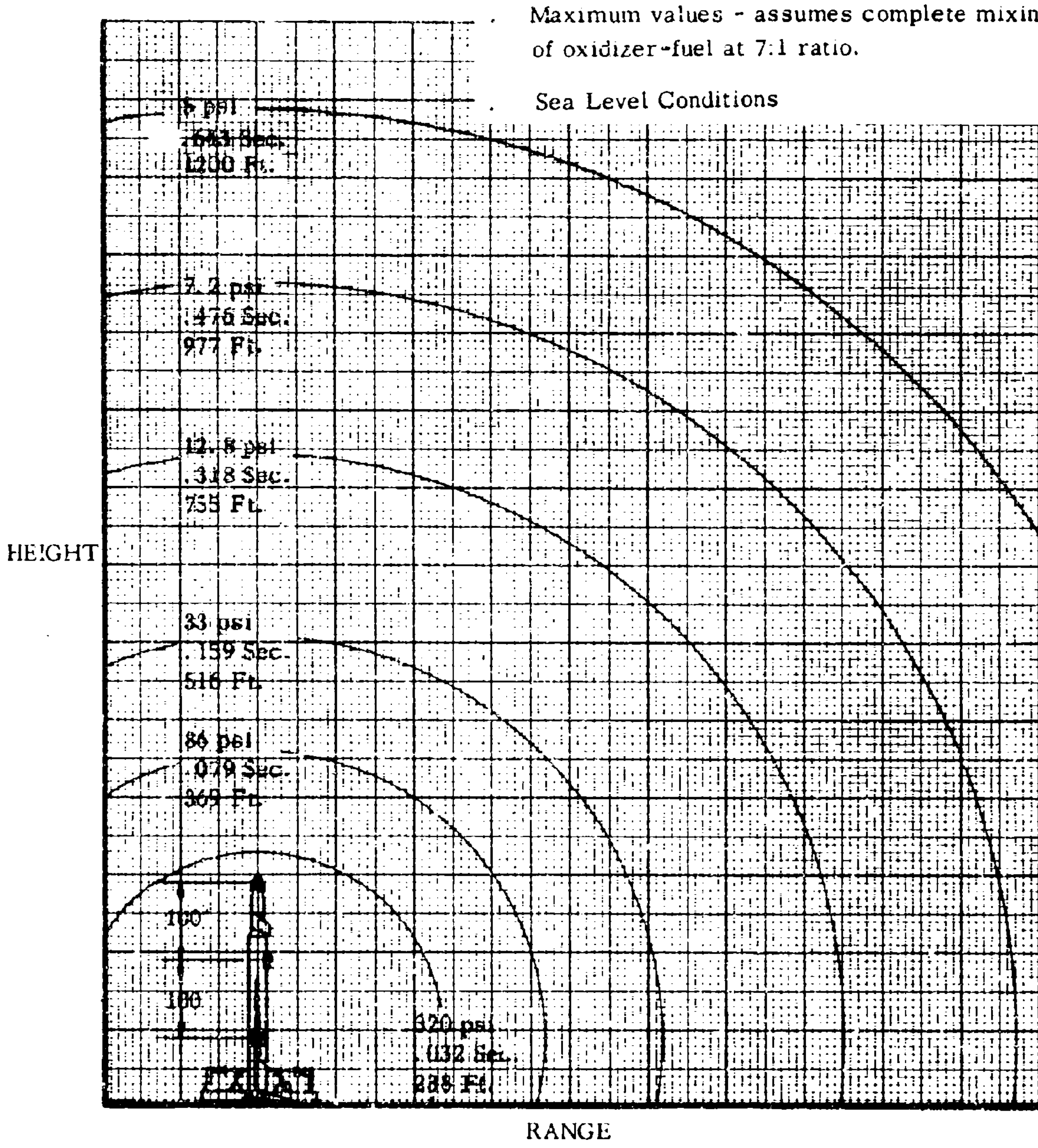


FIGURE 15 - 1-MILLION LB. TNT EQUIV. SHOCK WAVE PROPAGATION

SECTION 5

ESCAPE CONCEPTS

The information presented in Sections 3 and 4 has established the necessity of and requirements on escape concepts for a two stage manned recoverable aerospace vehicle. As expected, these results are identical with results of similar studies performed for single stage vehicles, e.g. References 1 and 2.

The next logical step in an escape criteria analyses is the selection of suitable escape concepts. For the present study, this task consisted of a review of escape concepts previously investigated or proposed for single crew compartment aerospace vehicles, e.g. References 1 and 2. The emphasis for the review was on any unique problems resulting from the two separated crew compartments which might influence the selection of an escape concept for a particular design.

In the selection of an escape concept for a particular vehicle design it is necessary to consider the tradeoff between the following factors:

1. Reliability of the main vehicle and the proposed escape concepts.
2. Escape concept complexity.
3. Flight envelope effectiveness.
4. Effect on vehicle performance characteristics such as payload capability.
5. Effect on vehicle structural integrity.
6. Development time and cost.

5.1 ESCAPE CONCEPT COMPARISON

The following escape concepts were reviewed:

1. Individual ejection seats
   a) Open
   b) Encapsulated
2. Individual capsules
3. Non-recoverable capsule with ejection seats
4. Recoverable capsule with ejection seats
5. Recoverable capsule
6. Capsule with escape tower
7. Combination of above

Not all of these concepts would totally satisfy the requirement for full flight envelope escape, however, each concept should be considered as a trade-off toward the overall mission.

Figure 16 presents a sketch of the basic concepts. Pertinent factors relative to each of the escape concepts considered were analyzed to determine the acceptability of these concepts to fulfill the requirements given in Section 3.

5.1.1 INDIVIDUAL EJECTION SEATS (OPEN AND ENCAPSULATED)

a. Sequencing of seat ejections and strict crew discipline required to minimize mid-air collisions. This problem is made more severe by the presence of two separated crew compartments.

b. Individual hatches required to permit ejection. This compromises the air tightness of the vehicle for its intended mission.

c. Seat positioning for high acceleration forces, if required, would be compromised by the requirement for seat ejection rails.

d. Ejection seats of standard design would not allow adequate protection nor separation distance when escaping from severe explosion and/or fire.

e. Ejection seats have no high temperature re-entry capability.

f. Open ejection seats are restricted to use at relatively low altitudes and dynamic pressures below 1500 to 2000 psf. This amounts to a very small portion of the overall mission envelope.

g. Survival equipment must be incorporated with each seat.

h. The downed crew could become widely separated on the ground and rescue operations hampered.

i. Individual ejection seats would create a vehicle payload weight penalty of approximately 375 pounds per seat for an open configuration and approximately 700 lbs. per seat for the encapsulated configuration. This would be the least weight penalty of the concepts considered.

5.1.2 INDIVIDUAL CAPSULES (EACH WITH FULL ESCAPE CAPABILITY)

a. Individual capsules with escape capabilities for the entire mission envelope would have the advantage of providing escape at least for some of the crew members in the event of damage to the cockpit area.

b. Each capsule would require independent detection, initiation and separation systems to accomplish escape. This would compromise the overall reliability and induce a severe weight penalty.

c. Each capsule should have all the characteristics of a single full crew capsule. This includes being aerodynamically stable, controllable, capable of re-entry, and recoverable. Integration of a capsule of this description would present definite problems of placement and volume, capsule separation, and of sequencing escape to minimize the hazard of colliding after separation.

d. The desirability of a single crew station with free access throughout to permit changes in duty stations would be restricted by the use of individual capsules. The second stage vehicle in particular should incorporate the single station arrangement due to the longer flight duration and orbital requirement. The booster or first stage does not necessarily require the crew to move about as it has a much shorter flight duration.

e. The structural integrity of the main vehicle, including its air tightness would be compromised by the incorporation of the independent capsules.

f. The downed crew could be widely separated if individual capsules were used and rescue operations would be hampered.

g. There is a sequencing problem which is made more complex by the presence of two crew compartments.

5.1.3 NON-RECOVERABLE CAPSULE WITH EJECTION SEATS (FULL CREW CAPSULE WITH EJECTION SEATS FOR FINAL RECOVERY)

a. The concept provides a single capsule for escape from any point within the mission envelope for both stages and utilizes ejection seats for the final crew recovery phase.

b. Non-recovery of main capsule eliminates requirements for capsule recovery system, landing impact devices and flotation gear.

c. In event of ground level escape, the capsule rocket motor must provide sufficient thrust for good separation distance with adequate altitude to perform safe seat ejections.

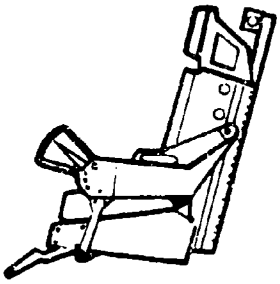
d. This concept would permit use of ejection seats directly if under suitable conditions of low altitude and low velocity.

e. Reliability of escape system compromised by double ejection sequence.

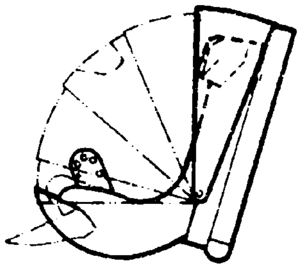
f. Capsule must be sufficiently stable to allow seat ejection sequence.

g. Most of the considerations discussed for ejection seats in Section 5.1.1 also apply to this concept.

h. With the exception of the ejection seat sequencing and separation trajectory problems, this concept has no unique problems in regard to its use in a two stage vehicle.

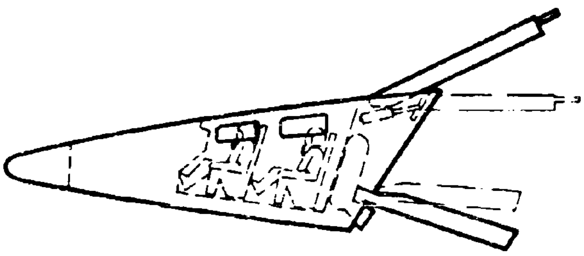


1. Ejection Seat (Sec. 5.1.1)



2. Individual Recoverable Capsule (Encapsulated Seat)

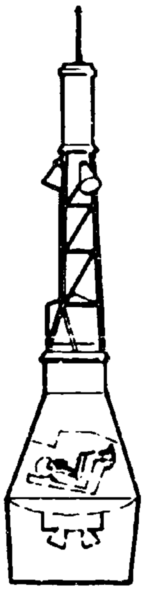
a. Limited Mission Escape Capability (Sec. 5.1.2)
b. Full Mission Escape Capability (Sec. 5.1.2)



3. Full Crew Capsule

a. Non-Recoverable with Ejection Seats (Sec. 5.1.3)
b. Recoverable with Ejection Seats (Sec. 5.1.4)
c. Recoverable w/o Ejection Seats (Sec. 5.1.5)

(Basic shape the same for all three versions)



4. Full Crew Recoverable Capsule With Escape Tower (Sec. 5.1.5)

Figure 16. ESCAPE CONCEPTS

5.1.4 RECOVERABLE CAPSULE WITH EJECTION SEATS

a. The primary escape system is the full crew capsule concept with ejection seat provided as a redundant system.

b. A capsule recovery system, landing impact device and flotation gear are incorporated in capsule.

c. Escape system complicated by addition of redundant seat ejection escape system. Reliability of overall system is compromised, and payload weight penalty is increased.

d. Escape system rocket motor provides sufficient thrust for good separation distance and adequate altitude to deploy capsule recovery system or use individual ejection seats.

e. There are no particular problems resulting from the application of this concept to two stage vehicles other than the ejection seat problems noted above.

5.1.5 RECOVERABLE CAPSULE

a. The recoverable capsule concept consists of a single capsule for each stage which encompasses the stage crew compartment.

b. No individual escape provisions are provided. This concept provides full crew escape capability throughout the vehicle mission envelope. Redundant recovery systems could be incorporated to back up the primary system.

c. Capsule incorporates stability and control system, emergency life support system, re-entry heating protection, maneuvering controls, landing impact attenuation device and flotation gear.

d. Crew remains together throughout escape and recovery, and can provide mutual assistance in rescue operation.

e. Crew seat can be constructed specifically to provide proper body positioning depending on forces applied.

f. This concept permits the least vehicle weight penalty for an escape system which is functional throughout the flight envelope.

g. The single capsule concept permits an optimum structure with maximum air tightness. Crew entrance and exit hatch is only opening required, other than windows, into crew compartment.

h. This concept can have the escape rocket motor in a self-contained installation or it can be mounted on a tower and jettisoned at pre-determined altitude, or mounted in escape capsule and carried throughout the flight.

Using the tower concept requires an additional rocket motor system carried in the capsule for use after jettisoning the tower. The rocket motor carried in the capsule is utilized for the retro-rocket in the event an orbital escape is required.

i. This concept has no inherent problems in application to a two stage vehicle.

5.2 ESCAPE CONCEPT APPLICATION TO VEHICLE CONFIGURATION

The various vehicle configurations considered in this study present different design requirements which directly affect the shape of the escape capsule.

The selection of a nose or pod capsule for a two stage vehicle is dependent primarily on the specific configuration geometry and is not influenced by the requirement of two separated crew compartments. The selection between ballistic and lifting configurations depends upon the escape corridor and any escape trajectory requirements, e.g., surface temperature limitations.

The location of the escape capsule on each vehicle, from the standpoint of escape, is significant only in assuring an upward escape trajectory. Vehicle configurations which have the second stage mounted on the underside of an HTOHL booster are assuming a high degree of risk for the second stage crew during the takeoff and initial pull-up due to the ineffectiveness of a downward ejected capsule at low altitude.

5.3 SELECTED CONCEPTS

As indicated previously the selection of an escape concept for a particular design depends upon tradeoff studies of the many factors involved. However, previous studies of single crew compartment aerospace vehicles favor the fully recoverable capsule concept discussed in Section 5.1.5. The present investigation for two stage vehicles has revealed no unique problems associated with this concept due to its application to two separated crew compartments.

In selecting fully recoverable escape capsule configurations the following criteria should be considered:

1. The capsule should be aerodynamically stable.

2. The capsule should have a stabilization and control system.

3. The separation interface should minimize separation interference effects.

4. The capsule crew compartment must be protected from the high temperature environment of re-entry.

5. The capsule must have provisions for a safe impact and in the case of water impact, flotation devices.

6. Communications and emergency life support systems are required.

7. Seat positioning may be required if excessive load factors are encountered.

Fully recoverable capsules can be classified according to capsule position on the main vehicle as nose capsules or pod capsules. Each of these classifications can be further divided into ballistic configurations or lifting configurations. Figures 17 and 18 present sketches of these two types. These particular configurations were discussed in Reference 5 and are presently being investigated under Air Force Contract AF33(615)-1131, "Investigation of Re-entry Escape System Separation Techniques From a Maximum Heating Re-entry Trajectory." These configurations were used to obtain the nominal separation performance characteristics presented in Section 6.

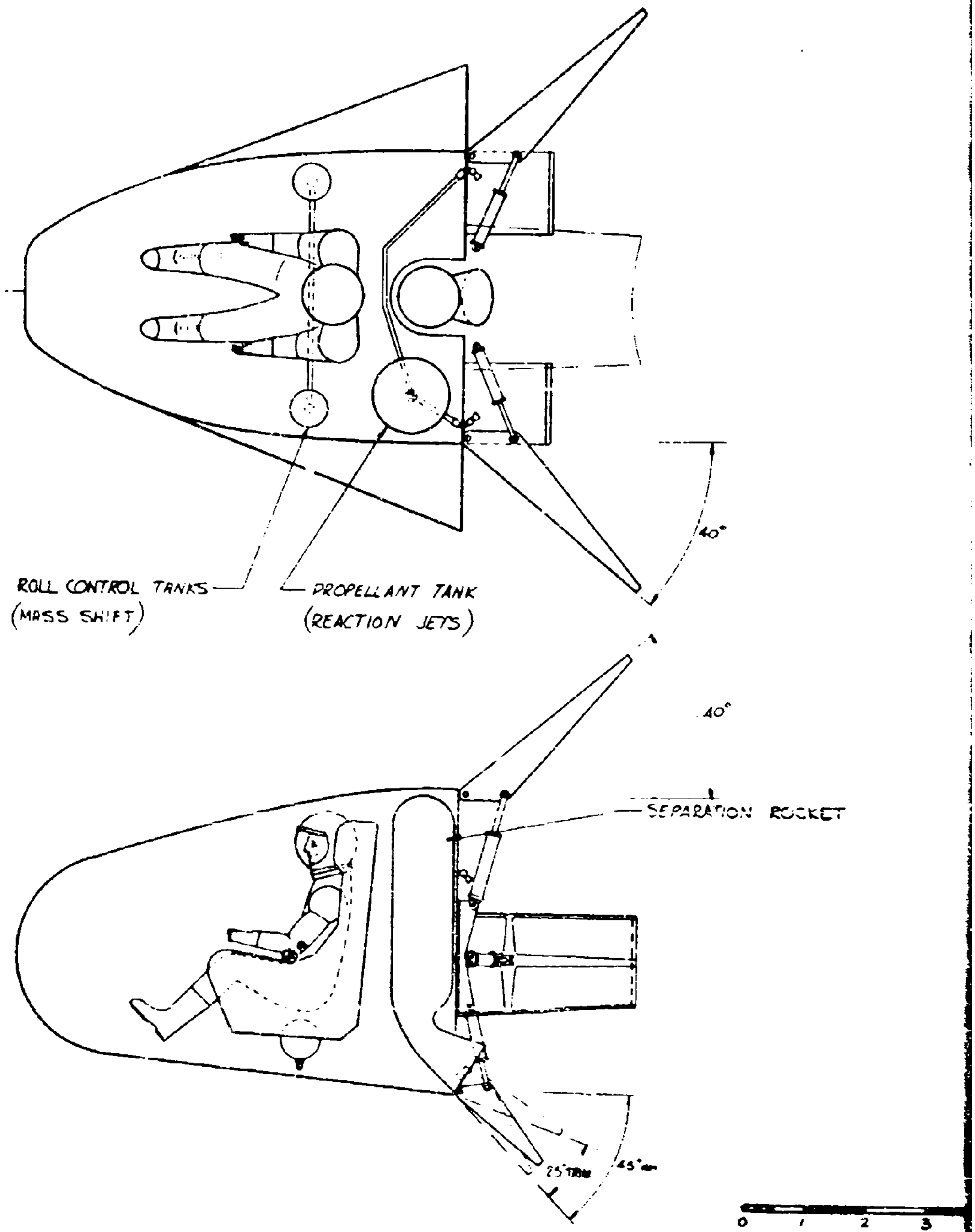
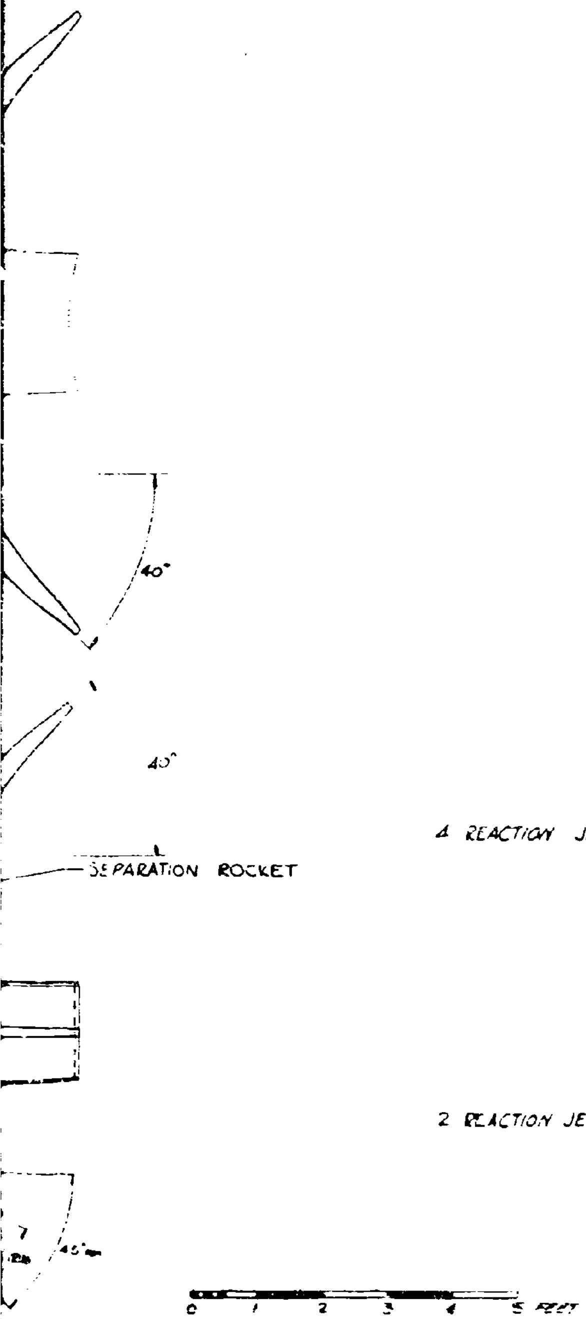


Figure 17 Ballistic Body

VEHICLE DATA	
REFERENCE AREA - PLANFORM	57 SQ FT
SIDE FLAP AREA - EACH	6 03 SQ FT
UPPER FLAP AREA	8 1 SQ FT
LOWER FLAP AREA - TOTAL	4 9 SQ FT
REFERENCE LENGTH ALONG BODY ℄	7.25 FT
WEIGHT (PRIOR TO THRUSTING)	2680 LB
WEIGHT (AFTER THRUSTING)	2500 LB
I_{xx} " "	190 SLUG·FT^2
I_{yy} " "	541 " "
I_{zz} " "	530 " "
I_{zx} " "	+56.7 " "

SEPARATION ROCKET DATA	
THRUST (NOM)	40,000 LB
TOTAL IMPULSE	40,000 LB SEC
PROPELLANT	SOLID
SPECIFIC IMPULSE (SL)	220 LB/LB/SEC
THROAT AREA	5.8 SQ INS
EXPANSION RATIO	3 1
CHAMBER PRESSURE	1000 PSI



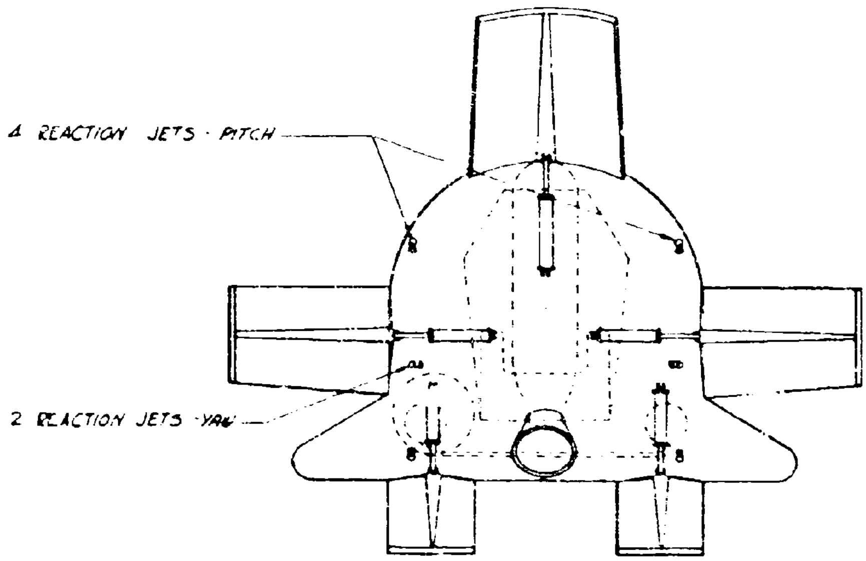


Figure 17 Ballistic Body - Nose Capsule

2

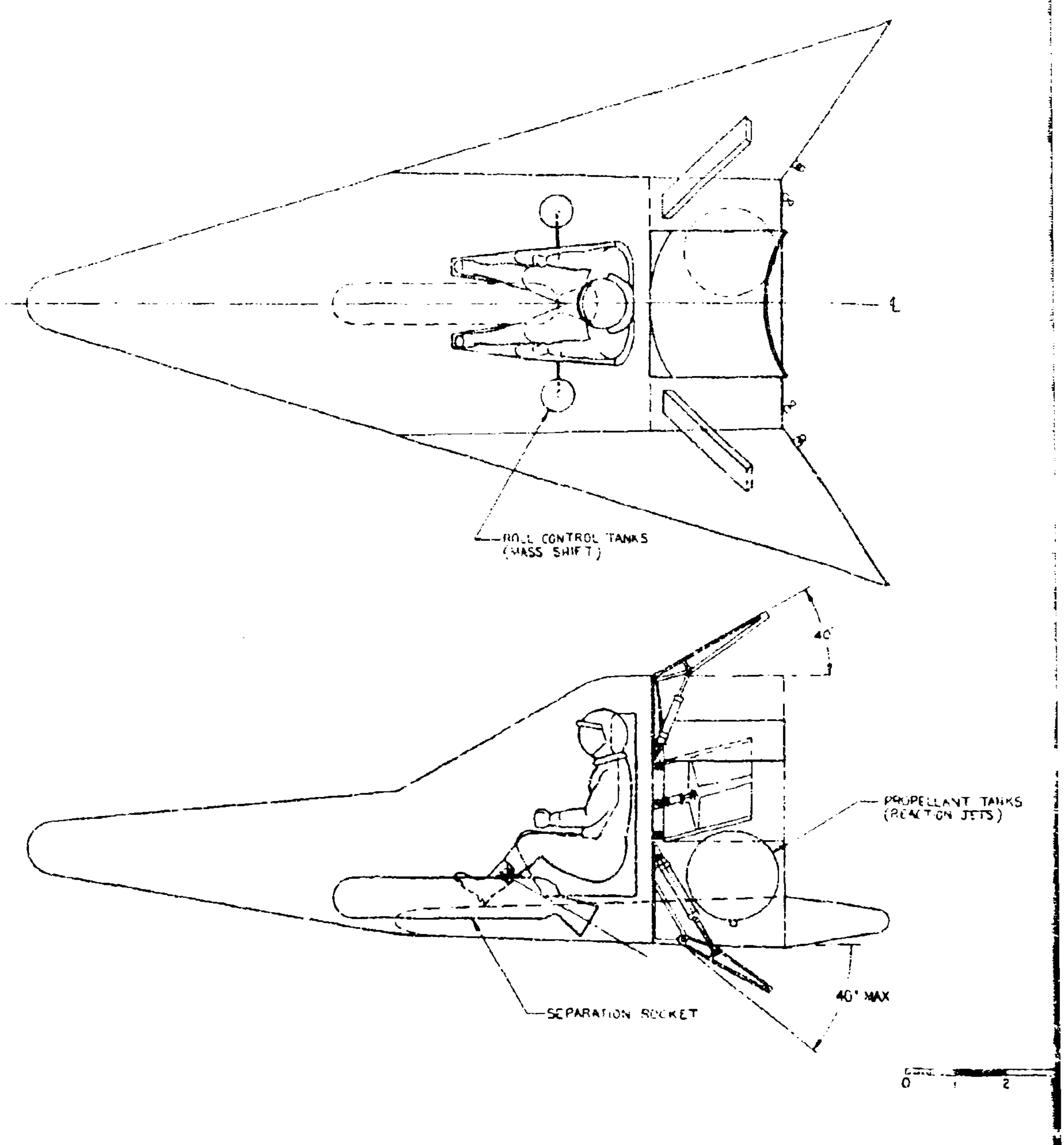
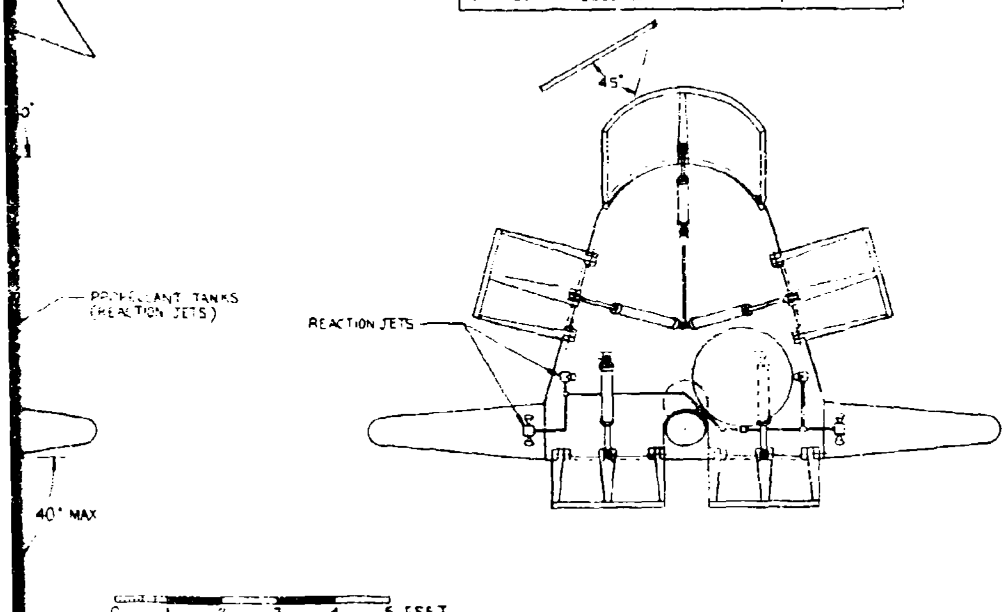


Figure 18 Lifting Body - Nose Capsule

VEHICLE DATA	
REFERANCE AREA - PLANFORM	85 SQ FT
SIDE FLAP AREA - EACH	38 SQ FT
UPPER FLAP AREA	94 SQ FT
LOWER FLAP AREA - TOTAL	60 SQ FT
REFERANCE LENGTH ALONG BODY ℄	151 FT
WEIGHT (PRIOR TO THRUSTING)	2615 LB
WEIGHT (AFTER THRUSTING)	2500 LB
I_{xx}	236 SLUG FT²
I_{yy}	97[illegible]
I_{zz}	956
I_{zx}	-34

SEPARATION ROCKET DATA	
THRUST (NOMINAL)	25,000 LBS
TOTAL IMPULSE	25,000 LB SEC
PROPELLANT	SOLID
SPECIFIC IMPULSE (SL)	220 LB/LB/SEC
THROAT AREA	3.7 SQ INS
EXPANSION RATIO	3 : 1
CHAMBER PRESSURE	1,000 PSI



Nose Capsule

2

SECTION 6

ESCAPE PROCEDURE

One reliability thesis often advanced is that any mission will turn out successful unless a mistake, or mechanism failure, occurs.

With the advent of more and more complicated requirements, long duration hypersonic aerospace missions, this thesis gains more and more in idealism and less and less in fact. Perfect performance without a mistake, without a malfunction, under a sustained and severely constrained complex becomes an unpredictable phenomenon, and failure counteraction emerges as a more thinkable thesis under the prevailing uncertainties.

Today's problems of advanced concept vehicles and crew engineering more than ever emphasize the great pressure of physical and metric constraints on functionality of vehicle and man. Functional design is called upon not only to reduce the likelihood of mechanism malfunction and human error but to increase the capability to recover in case of either event. Increasing the capability to recover requires situation sensitivity and common sense.

The practicable designation of recovery into components will require the conjunctive premises to be identified. Typically, a piece-wise action analysis of recovery from a mechanism malfunction or human error sets forth the following requirements:

1. Time to search, and search devices
2. Time to recognize, and perception devices
3. Time to decide, and decision devices
4. Time to effect, and manual/mechanical actions and/or devices

With regard to crew escape, these actions are the detection, initiation and separation operations.

In their specific instances of use in an escape system concept, the foregoing detection, initiation and separation action elements introduce varied and challenging demands upon the designer. The designer responds to most demand factors in terms of machine performance. Where the designer determines that a set of chance causes exists, design responses will be set forth in more complicated parameters perhaps, of man/machine cooperation.

These action elements, detection, initiation, and separation were investigated to determine what unique problems, if any, existed as a result of their application to crew escape provisions for an aerospace vehicle with two separated crew compartments.

6.1 DETECTION AND INITIATION

The detection and initiation task can be logically separated from the physical action of separation. Advanced manned aerospace vehicles have reached the point of complexity where malfunction detection and escape initiation are now a systems

operation. Since there is this concept of an abort detection warning and initiation system, (ADWIS), it should be incorporated into vehicle design studies at an early date rather than after a vehicle is designed.

The relationship of the ADWIS to vehicle design is presented in Figure 19. The area of study which relates the ADWIS to vehicle design is criticality and failure sensing. It would be an unusual circumstance where an escape system design would provide for escape from all conceivable hazard possibilities. Practical design brings demands of proper weight, space and cost tradeoffs or technology limitations and optimizations. Accordingly, likelihood distributions and densities of hazard occurrence require investigation as design criteria in addition to the determination of the possibilities of hazards or potential hazards. This is the criticality and failure sensing task noted on Figure 19. A mathematical definition of criticality is presented in Appendix 1.

The criticality and failure sensing task furnishes input data to the design of the ADWIS and also provides information for use in vehicle design iterations.

In the present generalized study there is no specific design for which a criticality study can be made. The information presented on detection and initiation in the sections which follow is therefore of a general nature.

6.1.1 DETECTION. Wherever they occur together, the functions introduced previously as search and recognition can be described with the generalization known as detection. Detection can be defined as the action or function of any device which indicates the presence of an entity of interest.

Detection premises may be closed, (where all possibilities are known) open or undefined. For a general example, suppose that for a certain course of action it is necessary to infer situation totality from fractional observations. Machine detection may prove unmanageable, and the human element prove indispensable for practical solution of the problem. The detection premises may be open or undefined. On the other hand, as the time domain becomes more restricted, the practicality of man over machine response becomes clearly reversed, the detection premises are consequently less open or undefined.

Implication of the human in the detection problem complicates the problem since it then becomes necessary to set forth a man/machine capability of achieving detection system success within some finite time.

With respect to the present study, detection refers to the detection of aerospace vehicle system malfunctions affecting crew safety.

The imminently boardable vehicle, its environment and crew are the diverse man/machine situation complex which the functional escape detection concept must contain. Each region must be surveyed for practically significant malfunctions or indications of impending catastrophe.

Detection in the present study has been limited to the area of sensors. Since there are some respectable contentions concerning whether or not the human element in a man/machine system can behave as a "sensor", consideration was limited to non-human sensors.

In the particular problem at hand, no peculiar sensor problems resulting from the concept of two separated crew compartments were uncovered beyond the perennial one of improving state-of-the-art.

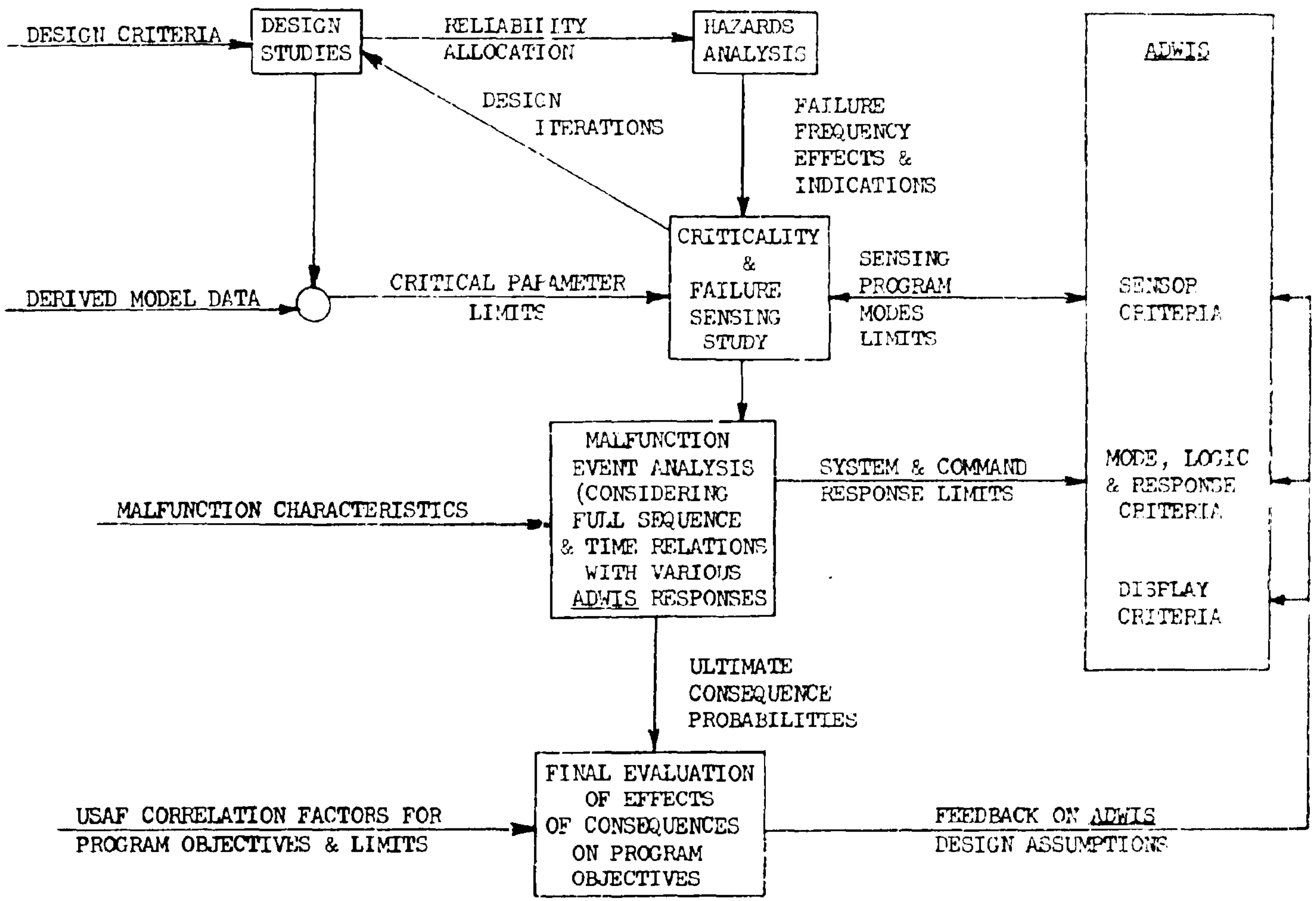


Figure 19 Abort Detection, Warning and Initiation System (ADWIS) - Data Interfaces

6.1.2 INITIATION. In the event of detection of a malfunction, the AIWIS must provide means for the best decision for responsive or evasive action. Where the required immediate action is not beyond reaction capabilities of abort commanders, either ground or on board, suitable display data must be provided at each command post. Where the immediate action required is beyond reaction capabilities of individual abort commanders, automatic or jurisdictional command must be predispositioned in the time and space complex in the manned vehicle operational complex which includes the vehicle and any supporting ground facilities. The parametric definition of such dispositions is the first step to the solution of timely, orderly and rational safety decisions.

All possible safety decisions (under emergency, or otherwise) can be classified simply as belonging to one of two sets:

1. Those decisions which alert or warn the endangered in time to take necessary responsive action

2. Those which do not

In the normal sequence of action following decision, we are at once concerned with the beginning of some positive act. In the present investigation, unless otherwise noted, the word initiation denotes the irrevocable beginning of the abort or escape act only.

Summing up all the initiation premises set forth thus far, we note that we are interested in decisions of warning and impending initiation, and decisions of no warning but initiation.

6.1.2.1 Problems. The two principal problem areas of the warning and initiation operation as considered in the present study are:

1. The use of sensed information; and

2. The jurisdiction over initiation

Use of Sensed Information. The use of sensed information is open and undefined so long as there remain open and undefined feasible options in the command and control complex. Problem definition here begins with defining the role of man in on-board systems.

The role of man can be assigned as support, i.e, augmentation for automatic programmed or ground controlled systems of the vehicle, or, the role of man can be assigned as one of an independent controller of the vehicle, supported and augmented by automatic programmed crew and ground informed systems. Here the man is used for his capability to change programs, make decisions and select alternate uses of equipment, tasks for which no machine has ever been devised.

In present VTOHL vehicles man acts in a passive role although studies are being made regarding the incorporation of man into the boost operation in a more active manner. Man is generally considered as the prime controller in presently envisioned HTOL vehicles.

The present study, however, is concerned with the escape subsystem and not the operations of the overall vehicle. The particular problem is the use of the sensed malfunction information provided by the detection system. Is the information given to man or an automatic device?

In contrast to man, a passive or automatic device is one of a singular nature. It is capable of performing only those functions - and calling out only those responses which are anticipated in its design. Thus, the automatic device can only react with predetermined response which is specifically connected to given stimulating conditions. Yet, despite the fact that the design of automatic devices must anticipate and contain the numerous possible states of operation involved, the automatic mode in certain circumstances becomes indispendable to functional escape system concepts. In other circumstances the automatic mode may not be preferred, or even justifiable, and there remain such circumstances to be defined.

Although the human element renders a system less predictable, this unpredictability may make possible a more desirable system characteristic. Here we identify flexibility as the most likely characteristic - flexibility as that which enables a manned system to take into account factors beyond those anticipated in design. The problem of conceptually defining feasible flexibility is the most challenging and important one of all. Accordingly, control display equipment is defined as the focal point of the at hand unique detection and initiation problem. Control display equipment is indispensable to making the difference between a vehicle in which all aboard are passengers and one in which there is command.

Jurisdiction. Escape initiation as an act is recognized primarily as the responsibility of the senior commander, yet a stricken multi-manned vehicle may under certain conditions have better crew survival probabilities otherwise. The problem here is to define the premises, the options and designate the commander who is sole authority for all action governing safety and integrity of the craft.

A simply represented complex of likely command posts for a hypothetical aerospace vehicle, as currently conceived, is indicated in the Venn diagram shown in Figure 20.

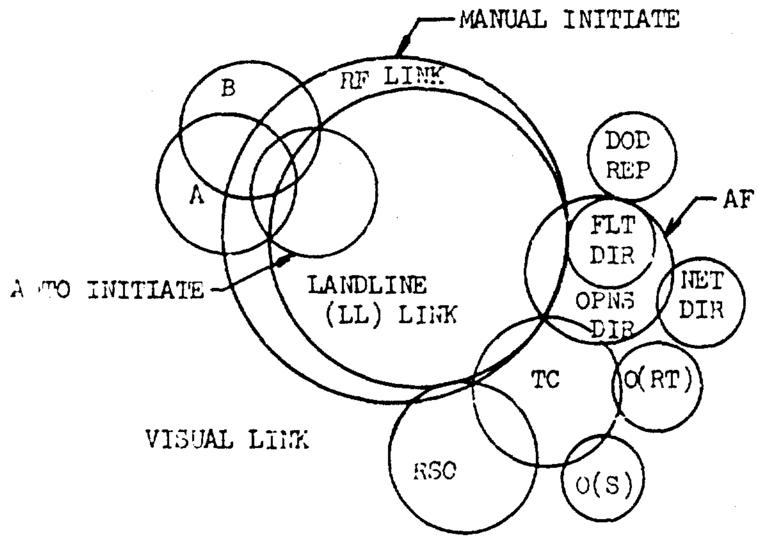
The commander by definition must be a primary situation determiner, decision maker, and control option selector. A vehicle commander in command can be effective only where he has the time to choose available options and operate in selected control modes in response to conditions he finds in operations. The vehicle commander faces a profoundly changing environment with incomplete information, and with little, or late, decision feedback. The problem here is to give the commander the "maximum useful" information as to any emergency.

The problem of "who and when" in the concept of shared or sequenced responsibility for advanced concept vehicles must be answered in a general manner since there is not a specific design under consideration.

6.1.2.2 Problem Solutions. This section will propose and evaluate solutions to the warning and initiation problems of: 1) use of sensed information; and 2) jurisdiction which were defined in Section 6.1.2.1.

Use of Sensed Information. Malfunction information can be distributed within the aerospace vehicle and to ground facilities. The concern herein is with the use of this data within the aerospace vehicle.

The objective of the use of sensed information is the simplest organization of information and its arrangement in any cockpit, so that the pilot can clearly understand the situation elements, connections, sequences, orders and what cues he may use and expect to use to effect a decision. The premises conceived must make clear the specific relationships which are important to the control decision task at any moment.



NOTES: DOD REP = Department of Defense Representative
AF = Responsible Air Force Command
OPNS DIR = Operations Director
FLT DIR = Flight Director
NET DIR = Network Director
TC = Test Conductor
RSO = Range Safety Officer
O(RT) = Real Time Observer
O(S) = Sighting Observer
A = Commander - Capsule A
B = Commander - Capsule B
RF = Radio Frequency

Areas of circles designate proposed abort jurisdiction notions. The relative size of the areas is arbitrary. Tangent and overlapping areas denote conceivable abort jurisdiction unios. Overlapped areas designate proposed common elements of the union. Precedence is indicated in a direction radially outward from center, i.e., starting with overlapped link for initiation in the abort jurisdiction union of interest

Figure 20 Venn Diagram of Possible Command Posts

Initially the subject will be discussed in terms of a single command post. Qualifications introduced by the concept of two command posts will then be introduced.

Of the ways conceived to facilitate the vehicle commander's decision making task, the combination of selective automatic control and parallel human effort has been adopted as most promising where coordination of details of operations task sharing or task delegation gravitates around the on-board centered command function. Concept options and premises conceived for the on-board centered command action are presented subsequently, but first it is significant to discuss possible safety-oriented decisions.

Table 7 presents the proposed decisions and decision types. The main division is between warning and initiation decisions. Within each subdivision the decisions may be automatic or manual. In the case of manual initiation automatic backup should be provided.

TABLE 7

COMMAND POST DECISIONS AND DECISION TYPES

CLASS		DECISION	TYPE
INITIATION	MANUAL	EJECT!	OPERATIONS
		ABORT! (TO EJECT)	COMMAND
			OPERATIONS
	AUTO	EJECT!	COMMAND
			OPERATIONS
WARNING	CAUTION:	EJECT IMMINENT!	COMMAND
			OPERATIONS
		ABORT IMMINENT!	COMMAND
			OPERATIONS
	NOTE:	CANCEL:	COMMAND
			OPERATIONS

In the terminology used herein abort refers to mission abort, which includes but is not limited to escape. Eject refers to escape. An operations decision is defined as that decision initiated at a responsible command post as

a result of evaluating available and sufficient operations data. A command decision is defined for a given command post as an operations decision initiated at another responsible command post. For example, in a first stage vehicle a command decision would be one made in the second stage or on the ground and given to the first stage.

All responsible command post decisions must terminate in on-board responsive action. Where a command decision is escape initiation or eject, on-board follow-up action is automatic. Where escape initiations are originated onboard, the action can be either manual or automatic. The onboard manual options which admit the desired flexibility in the use of sensed information must be based on the notion of early warning or preinstruction.

If we consider cockpit circumstances which are sensitive only to the chance occurrence of a particular malfunction, say N, then N as a particular event can be said to have a constant onset rate. The waiting time for the event N to occur is exponentially distributed, the hazard rate is constant, that is, N is equally likely to occur during any part of the interval of time we are searching and we really have very little information relevant to decisions anticipating catastrophe, if that is what malfunction N represents in reality. Now take the case of the occurrence of a different malfunction, say N-2. If N-2 belongs to a prior known set of malfunctions terminating in N, that is, N is the catastrophic or absorbing malfunction, N will have a conditional onset rate different after N-2 or for that matter any malfunction (N-i) occurs. The best estimate of such onset rates will depend on the preconceived and/or demonstrated influence of the occurrence of the particular (N-i) on malfunction N. This influence will likely be inconveniently variable or non-stationary, that is, its magnitude will change with time and transition state. However, if the state influences are so taken as to sensibly approximate stationarity, then any particular malfunction (N-i) starts a constantly deteriorating process which terminates in malfunction N. The waiting time to catastrophe can be counted down by observing the transition time between any two successive events, and the deterministic motion of waiting time to safety begins to emerge from a complex background.

As we have noted before, we should expect that available data and operational requirements will not allow convenient outcomes of stationarity. However, state influences may be grouped, or jumped across inconvenient levels. (In this way we may more smoothly approximate any deteriorating process at the cost of complicating the reference concept of simple stationarity). Now if the variously obtained indications of influence on malfunction N, that is, N (N-i), i = 1,2,3, are ordered and grouped in levels with respect to their best estimated conditional onset rates, we gain an infinitely improved position over the isolated event or Poisson situation. We are now enabled to observe respectable cues and verifying sequences relevant to decisions anticpating malfunction N. Such is the basic concept of malfunction sequence monitoring, to be implemented in an on-board malfunction warning display (MWD). Figure 21 presents a schematic drawing of this MWD concept.

In the proposed on-board oriented concept, the aim is to most gainfully integrate the human complex into a functional man/machine escape system. To properly implement the concept, the details must preserve the uninhibited functioning of designated human command elements in the outer emergency loops of command and control, while still providing practical monitoring of mission progress or inner functional status of the vehicle.

Onboard the functional status of the vehicle will be indicated by simple light dropouts and turn-ons, reflecting caution, holding, warning status, and

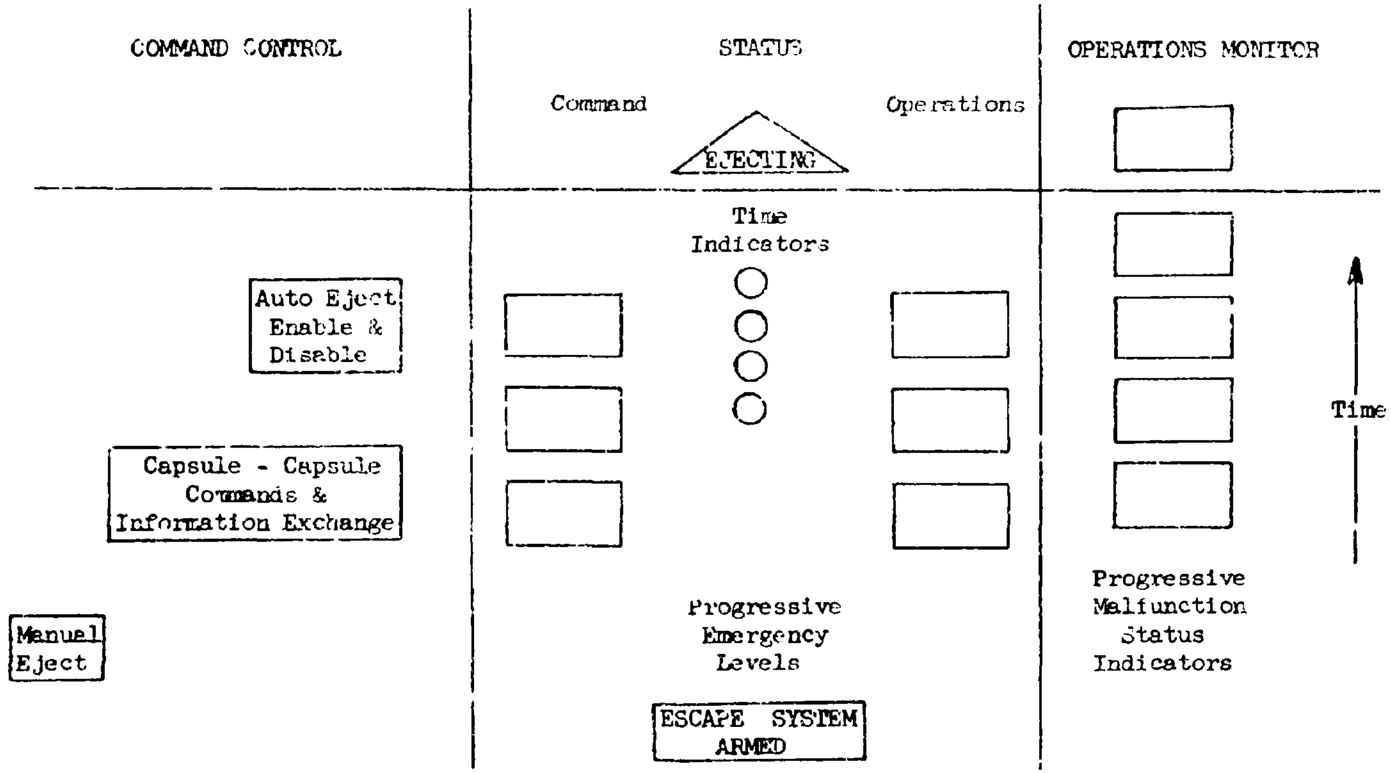


Figure 21 Malfunction Warning Display - Concept Schematic

command and operations audio-visual cues, sequences. The abort and escape parameter criteria themselves will depend on vehicle systems hazards analysis and criticality during countdown, flight, individual stage operation, problem degradation and decision window size.

There are many times during the operation when automatic initiation is unnecessary, or unjustified, because the time available for better decisions and the availability of emergency capability. During other times automatic initiation is mandatory, because the time between certain malfunctions and vehicle loss are shorter than human decisive action. The notion of a decision window and its including parameter, "waiting time to expected safety" is introduced in Figures 22 and 23.

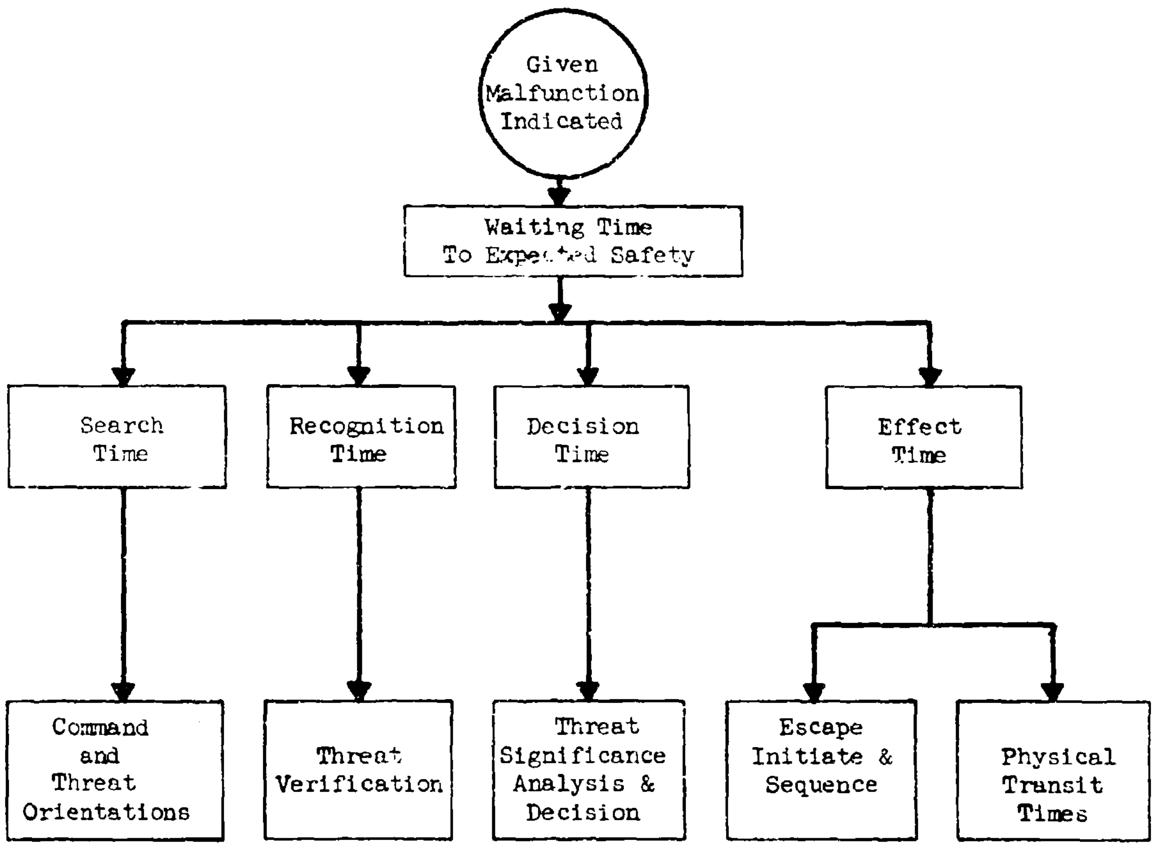
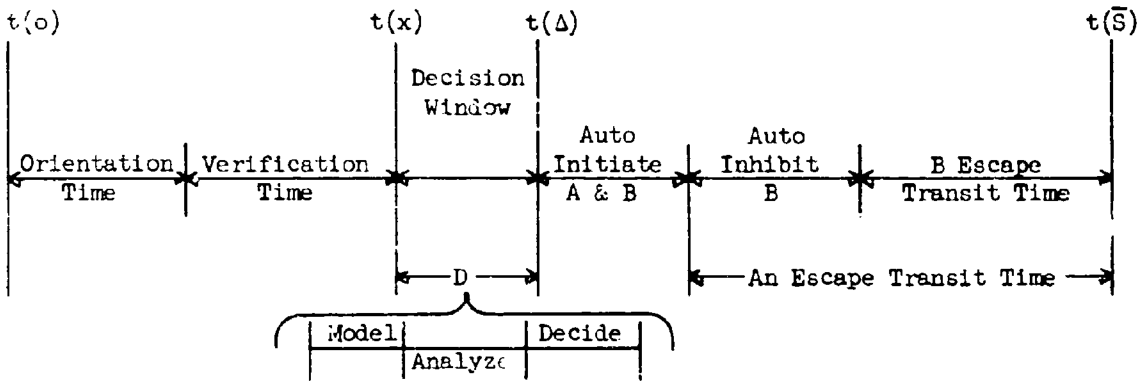


FIGURE 22 - PRINCIPAL COMPONENTS OF WAITING TIME TO EXPECTED SAFETY

Figure 22 presents the principal components of waiting time to expected safety after a malfunction has been indicated. A more detailed time sequenced arrangement of these elements of waiting time to expected safety is given in Figure 23. The proposed decision window is that period of time, D between malfunction verified at t(x) and the time of the last possible pre-escape command act necessary to effect the required escape, t(Δ). When the available decision window closes (D = 0) at t (Δ), escape is automatically initiated. Figure 23 indicates provisions for automatically inhibiting the separation of one capsule if it is contingent upon the prior separation of the other capsule. The implementation of such an inhibiting characteristic in any specific system is not conceived as a problem.

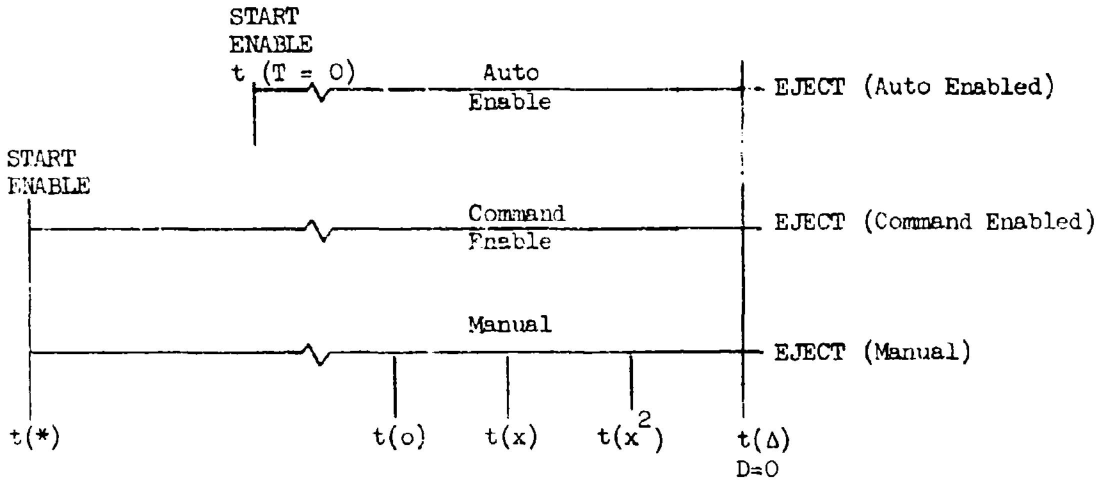


t(o) = Time of malfunction indicated
t(x) = Time of malfunction verified
t(Δ) = Time of escape initiation
t(S̄) = Time of expected safety

FIGURE 23 - ELEMENTS OF WAITING TIME TO EXPECTED SAFETY

The size of the decision window, D, is a variable contingent upon the particular malfunction under consideration. The value of D will determine the requirements for automatic detection and escape initiation backup. Under certain circumstances the commander should be provided with automatic backup as an option. Figure 24 shows proposed decision window backup provisions.

After vehicle takeoff or launch the vehicle commanders preselected option, which is indicated in Figure 24 as AUTO ENABLE and provides for EJECT (AUTO ENABLED), may be enacted. The COMMAND ENABLE refers to the provision for command type decisions, i.e., decisions from a different command post, e.g., ground facilities. This option will most likely be enacted immediately after vehicle escape system arming on the pad. The decision window of course is principally backed up with MANUAL for EJECT (MANUAL OVER AUTO) beginning with vehicle escape system arming. Obviously, the available decision window closes with any event of escape initiation prior to D = 0.



$t(*)$ = Time of escape system arming
$t(T=0)$ = Time of vehicle initial airborne motion
$t(x^2)$ = Time of x-onset cue

FIGURE 24 - PROPOSED PROVISIONS FOR DECISION WINDOW BACKUPS

The decision that any available decision window will be "waited out" is a privilege belonging solely to the commander. His decision will be based on his appraisal of the likelihood that additional information in the waiting time might:

1. Allow recovery of the failing mission and the difference in the consequences, or

2. Make a manual over automatic pre-empt of action more unalterably advisable.

Manual overrides of the short decision windows associated with EJECTION IMMINENTS ($D \leq 5$ seconds), will be almost certainly restricted to alternative (2) above. During the more frequently occurring decision windows of $D > 5$ seconds, manual overrides will predominantly include those of alternative (1) above.

It is this availability of a decision window in many malfunction circumstances which makes the concept of malfunction sequence monitoring possible.

After on-board vehicle escape system arming, it is proposed that the commander monitor malfunction characteristics through the time sequenced Malfunction Warning Display, MWD, presented schematically in Figure 25. Prior to the emergency level of EJECTION IMMINENT, the commander will operate through the X-button, y light, coded command/operations status keyboard. Subsequent to EJECTION IMMINENT the MWD serves as a status display. The MWD consists of status operators and indicators (center), command operators and indicators (left) and an operations

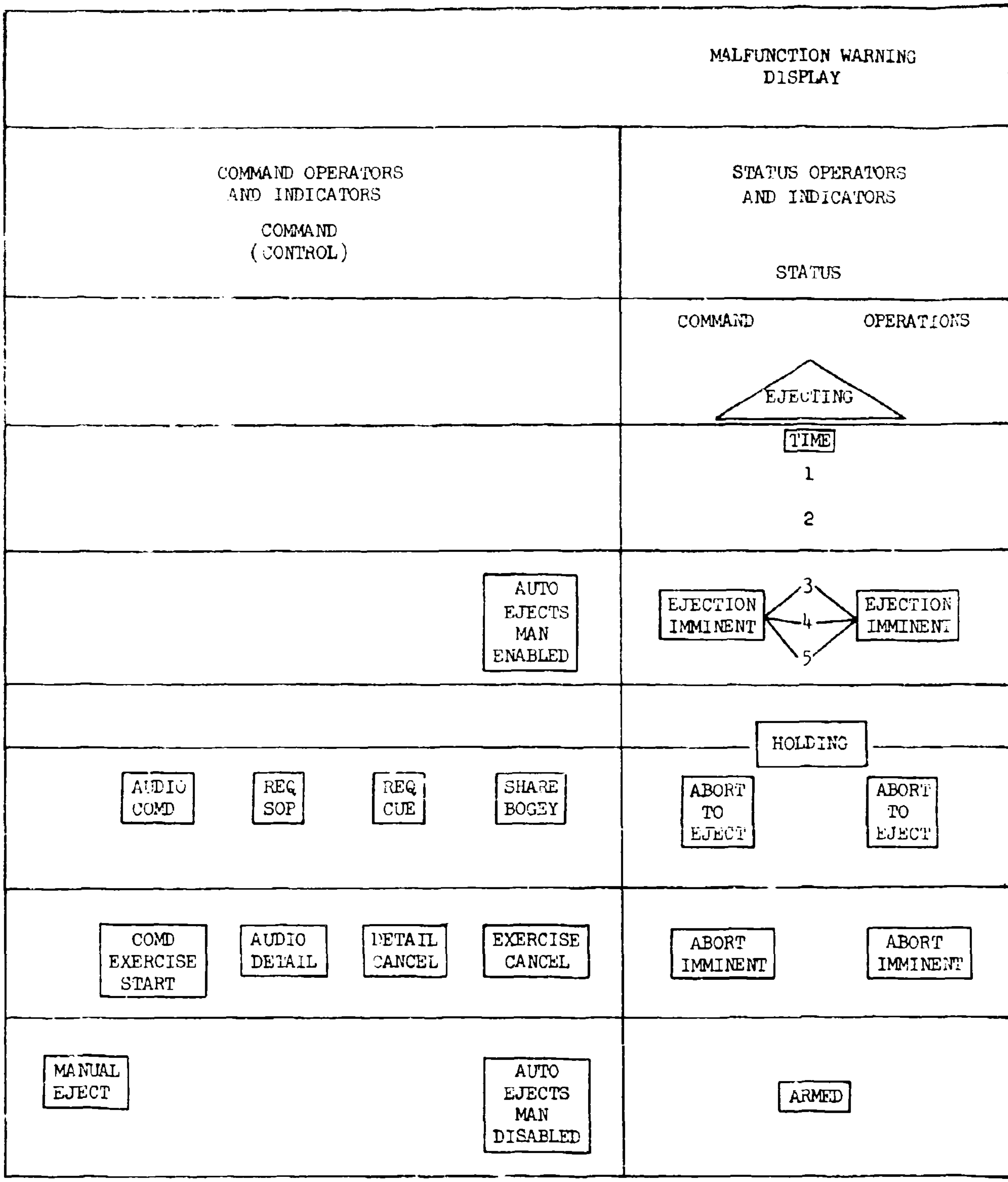
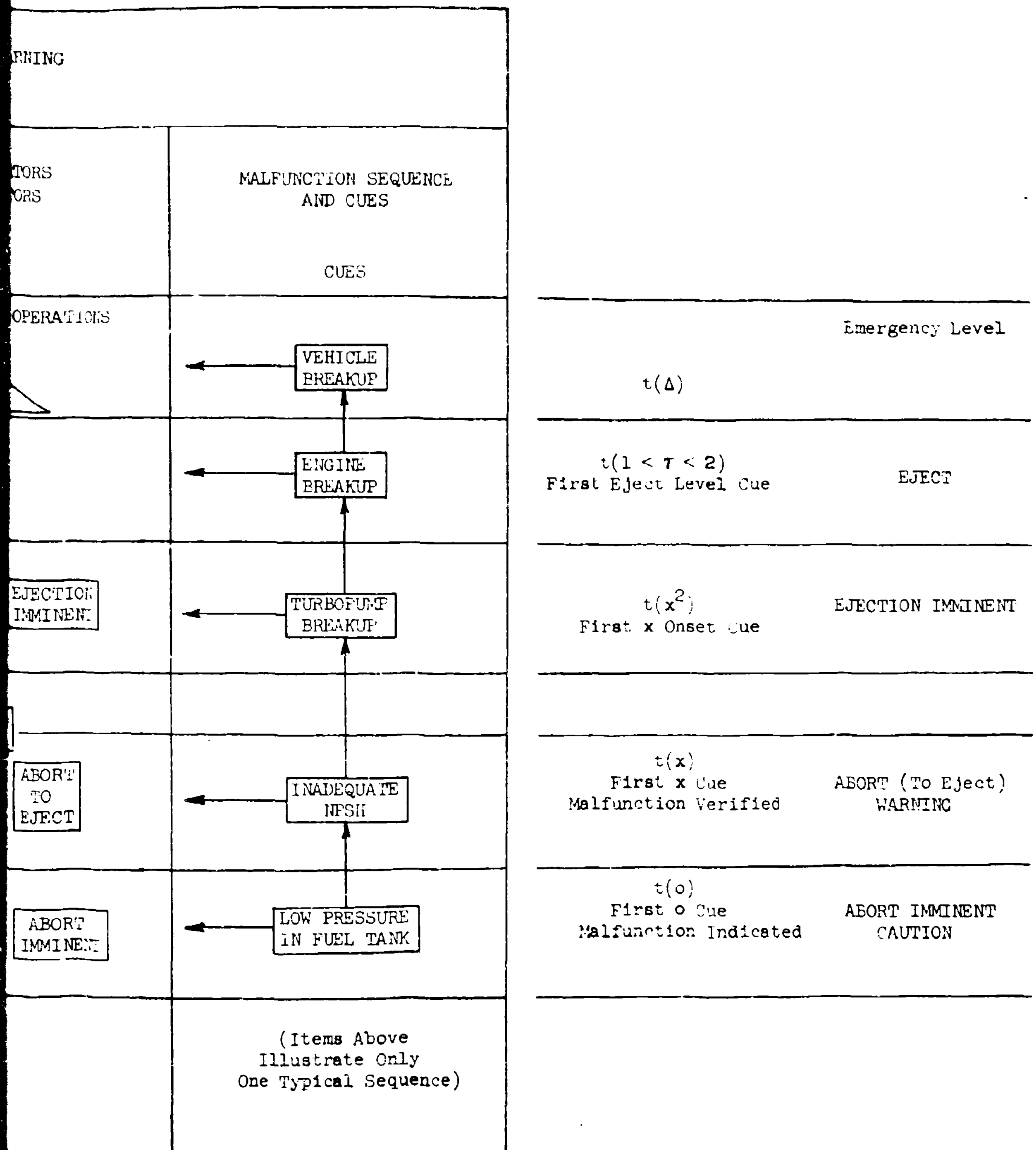


FIGURE 25 MALFUNCTION WARNING



NCTION WARNING DISPLAY SCHEMATIC

cue and malfunction sequence "tree" (right). Figure 25 shows the MWD abbreviated on its right, i.e., with only one typical "branch" set of malfunction sequences and cues for a hypothetical VTOHL shown. For the same vehicle a more complete likely operations cue and malfunction sequence "tree" is shown in Figure 26. The principal mathematical concepts necessary to the evolution of this "tree" concept are presented in Appendices 1 and 2.

Although presented for a VTOHL vehicle the MWD concept is also applicable to HTOL vehicles. In application to specific vehicles the principal differences would be in the operation cues presented on the right side. As conceptually visualized an MWD would be located in each crew compartment and designed so that the second stage could monitor first stage performance prior to staging and its own performance after staging.

During the course of command, operations, verification or error prior to EJECTION IMMINENT, the command/operations status lights (center board) and cue lights (left) will guide the commander. At the time a command is acknowledged, or on board initiated, the responding commander pushes the appropriate operator status button. The associated routine-option group located on the left will be enabled, allowing an exchange of inputs to be fed automatically or otherwise between the two command posts.

The objective of the upper part of the status and cue portion of the display (EJECTION IMMINENT to $t(\Delta)$ is to provide the best information regarding the size of the decision window. Operation during this period is restricted to the option of a manual pre-empt of the automatic ejection sequence. The selection of this option by the commander would depend upon the way in which the EJECTION IMMINENT emergency status was developed as given by the cues on the right.

The interval from $D = 5$ to $D = 2$ is classified at the emergency level of EJECTION IMMINENT. The interval from $D = 2$ to $D = 0$ is the EJECT level. It is proposed as a design objective that the off-board command decision of EJECTION IMMINENT occur no later than $D = 5$. An on-board EJECT level of 2 seconds is proposed, since this is approximately the minimum time interval in which a cue could be recognized and manual initiation affected. It is noted that a commanded automatic eject is also possible in this time period.

The on-board developments following the time of EJECTION IMMINENT status are shown in Figures 27 and 28. Figure 27 presents the developments for EJECTION IMMINENT developed by an on-board x-onset cue indicated on the right side of the MWD. Depending on the nature of the cue, one of the on-board 5, -4, or 3 second EJECTION IMMINENT countdowns begin. The countdown continues in real time unless a further overriding cue develops or a commanded automatic eject occurs. In the case of an overriding cue the count is autoshifted down to a lower value followed by immediate manual eject or automatic ejection override at $D = 0$. If during an on-board developed EJECTION IMMINENT status a commanded EJECTION IMMINENT occurs, the count is autoshifted to $D = 2$ since the situation has degraded.

Figure 28 presents the developments subsequent to EJECTION IMMINENT started by a command x-onset cue developed in command channels and communicated to the on-board commander. This situation begins the on-board five second EJECTION IMMINENT countdown. The countdown continues in real time unless an overriding cue develops. In this event the subsequent developments are the same as discussed for on-board developed EJECTION IMMINENT.

Figure 29 summarizes the sequence of events and emergency levels leading to the EJECTION IMMINENT status.

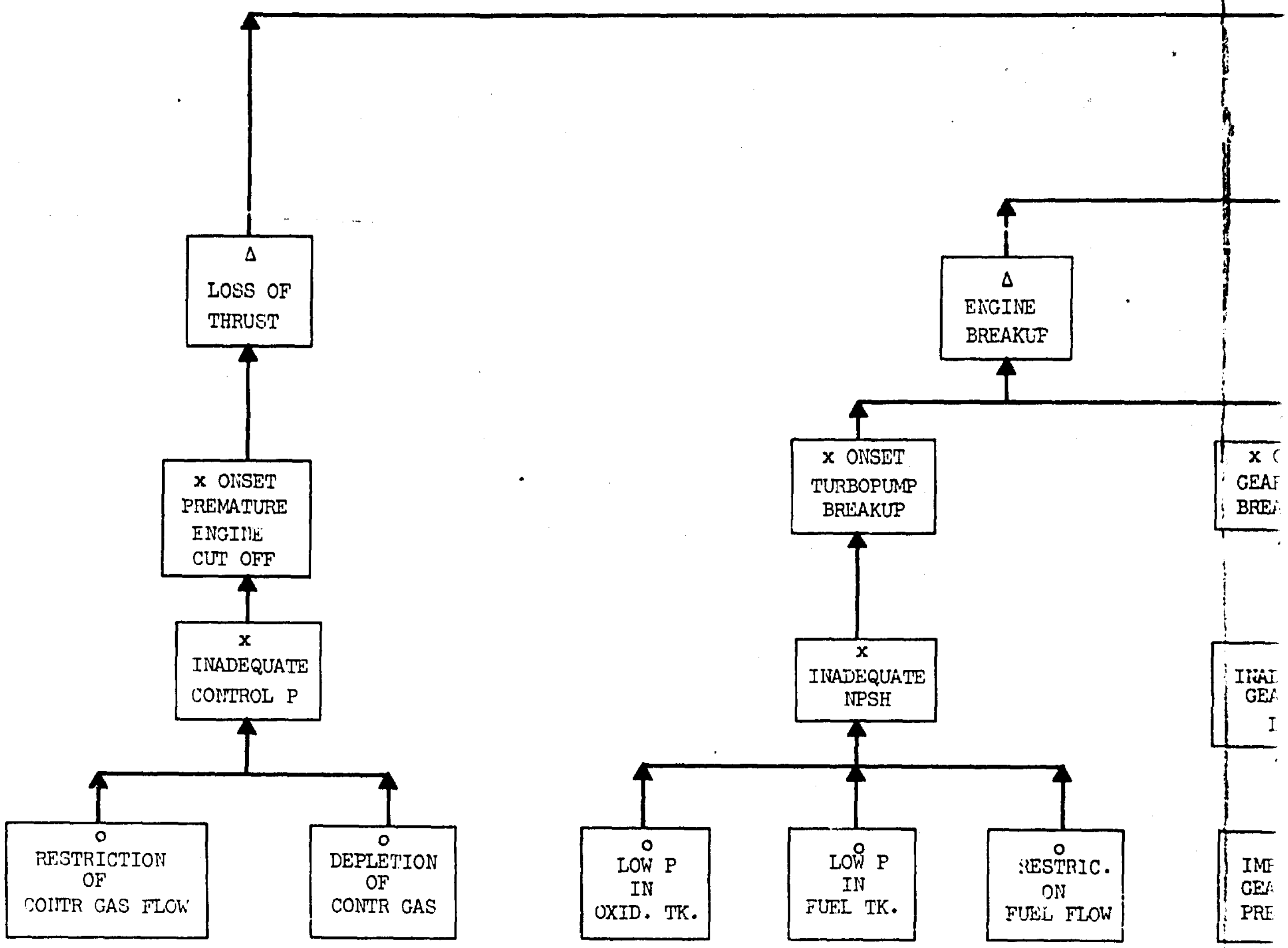
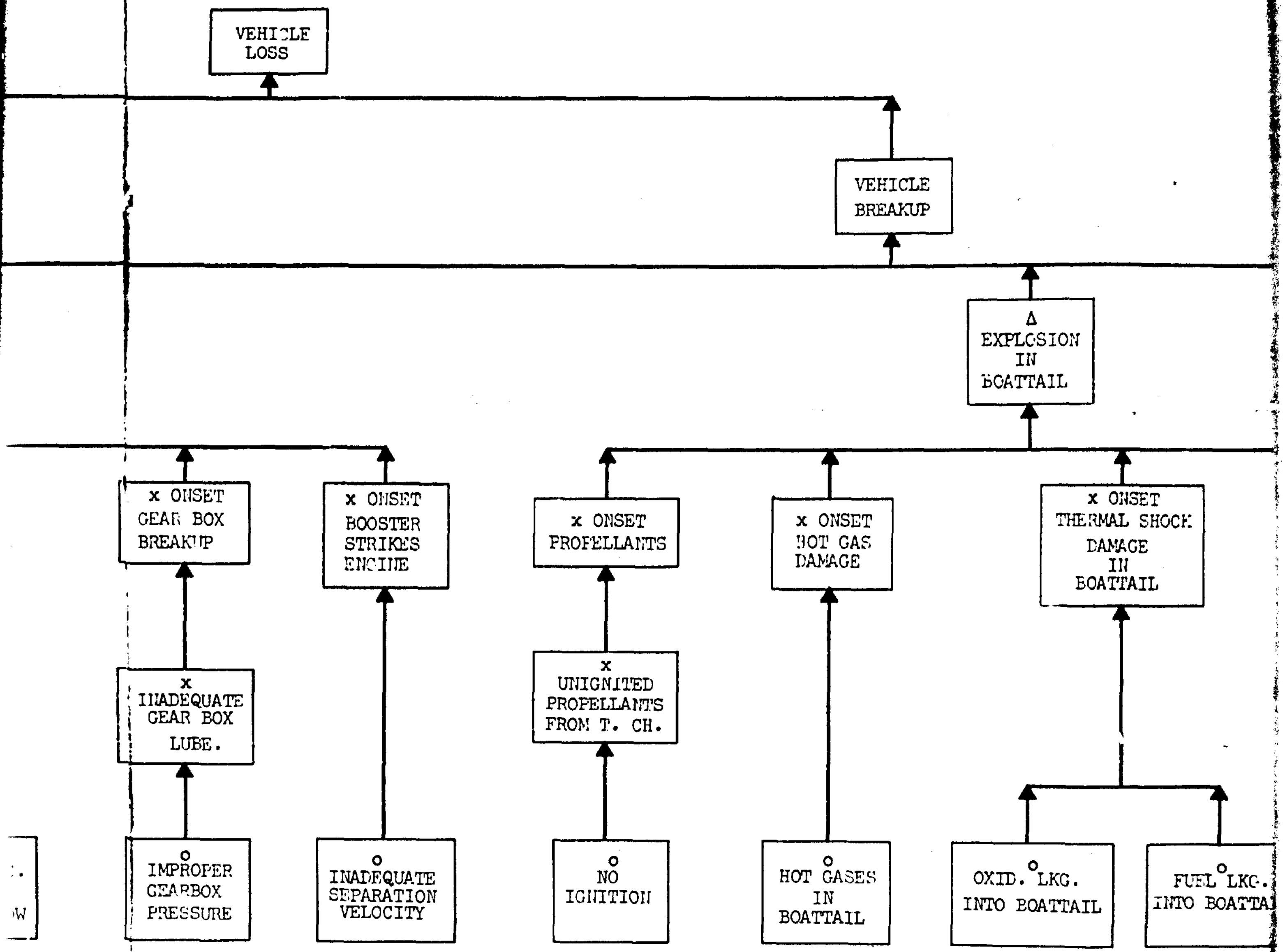
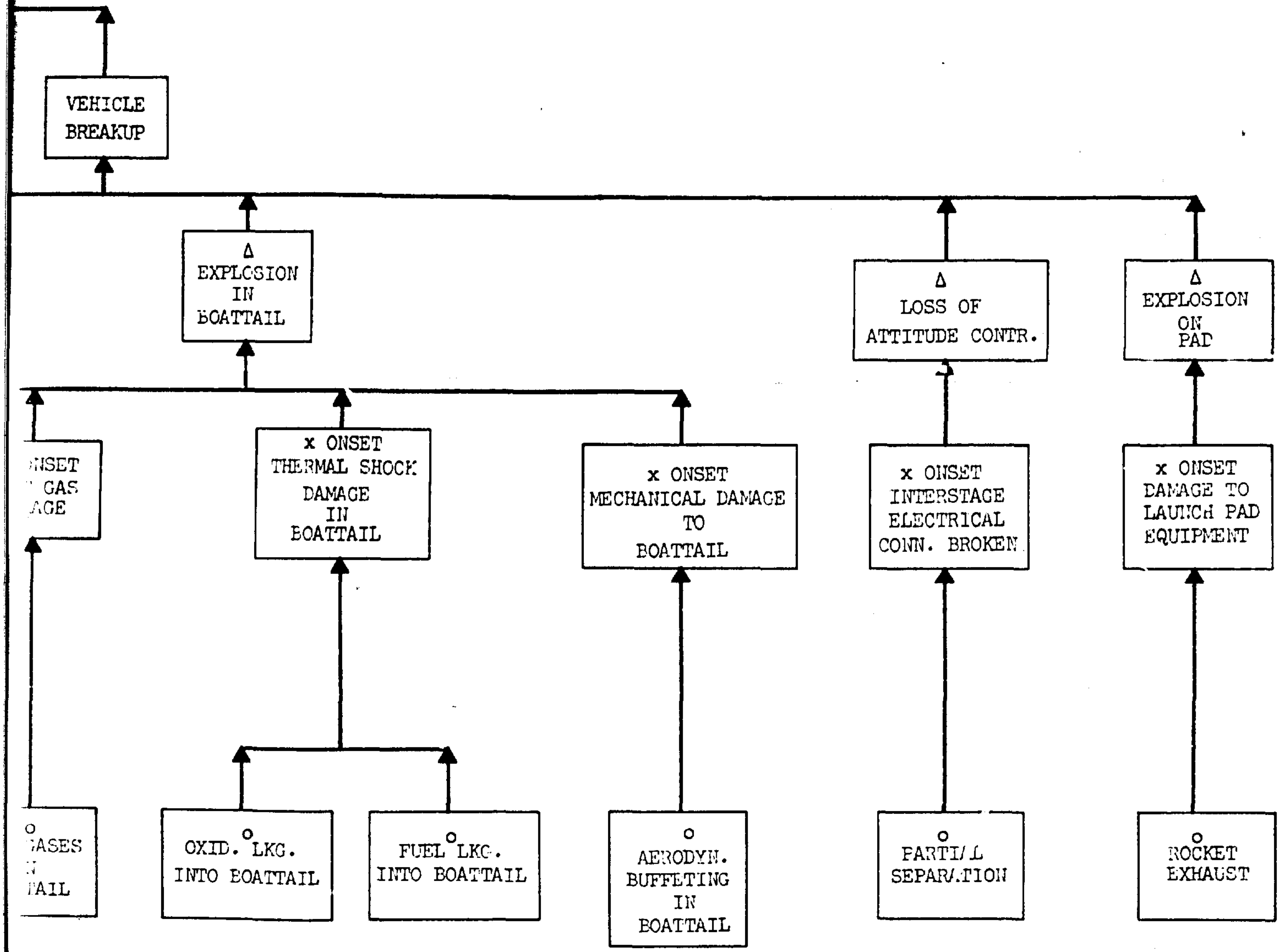


FIGURE 26 TYPICAL



RE 26 TYPICAL MALFUNCTION CUE AND SEQUENCE MONITORING "TREE"

2



VEHICLE BREAKUP
Δ EXPLOSION IN BOATTAIL
Δ LOSS OF ATTITUDE CONTR.
Δ EXPLOSION ON PAD
x ONSET THERMAL SHOCK DAMAGE IN BOATTAIL
x ONSET MECHANICAL DAMAGE TO BOATTAIL
x ONSET INTERSTAGE ELECTRICAL CONN. BROKEN
x ONSET DAMAGE TO LAUNCH PAD EQUIPMENT
o OXID. LKG. INTO BOATTAIL
o FUEL LKG. INTO BOATTAIL
o AERODYN. BUFFETING IN BOATTAIL
o PARTIAL SEPARATION
o ROCKET EXHAUST

3

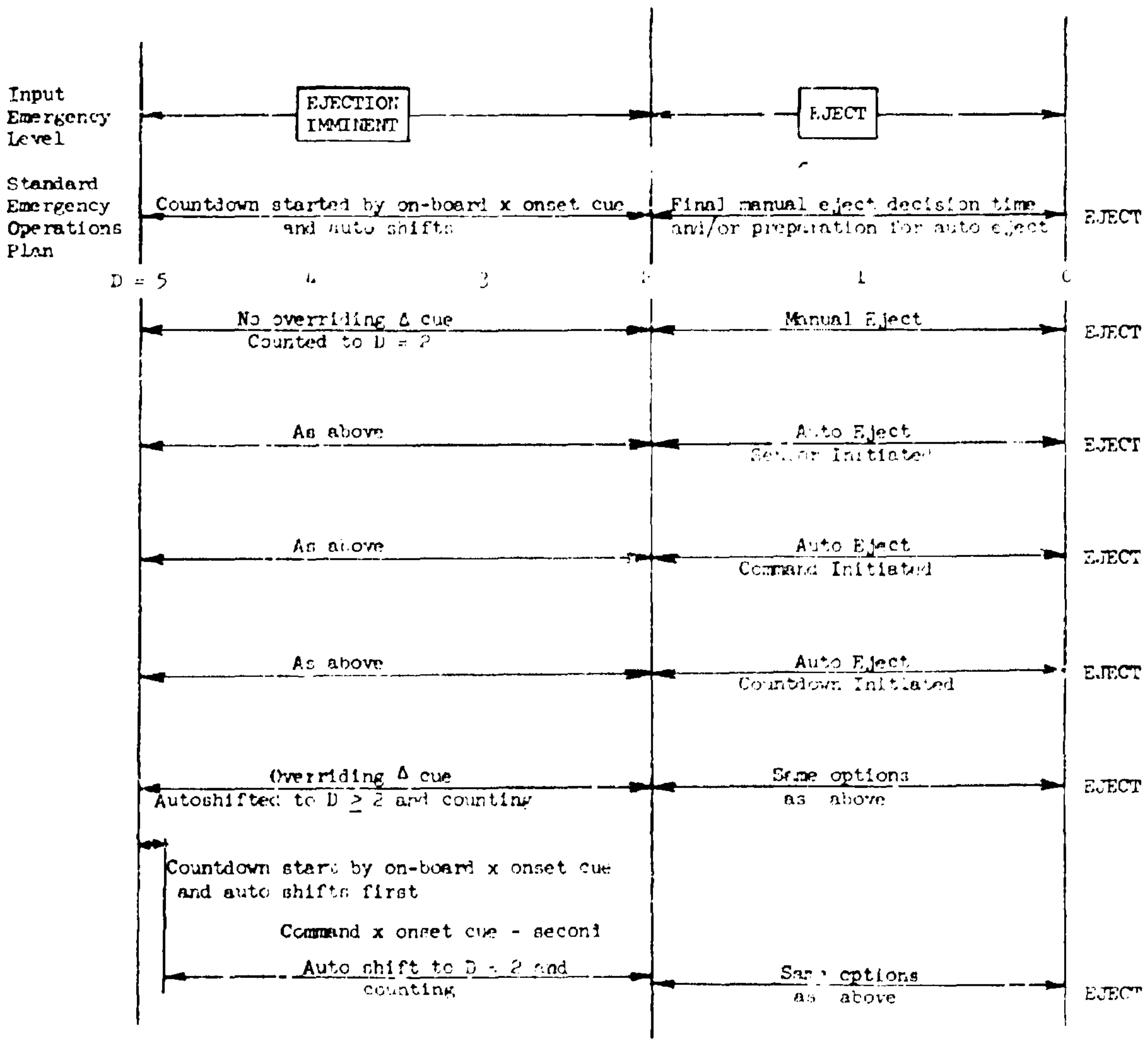


Figure 27 On-Board Developments Following On-Board Developed EJECTION IMMINENT Status

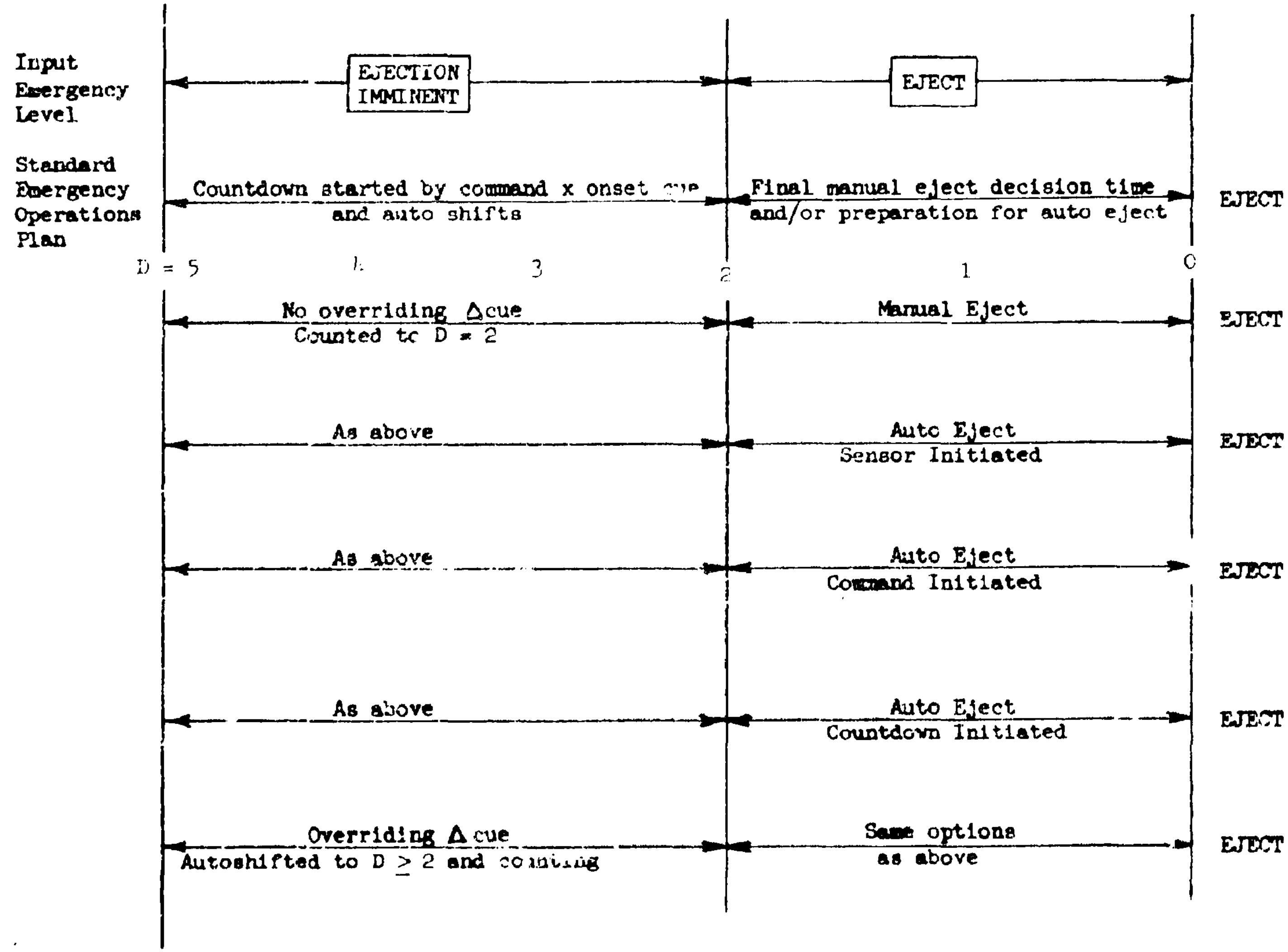


Figure 28 On-Board Developments Following Commanded EJECTION IMMINENT Status

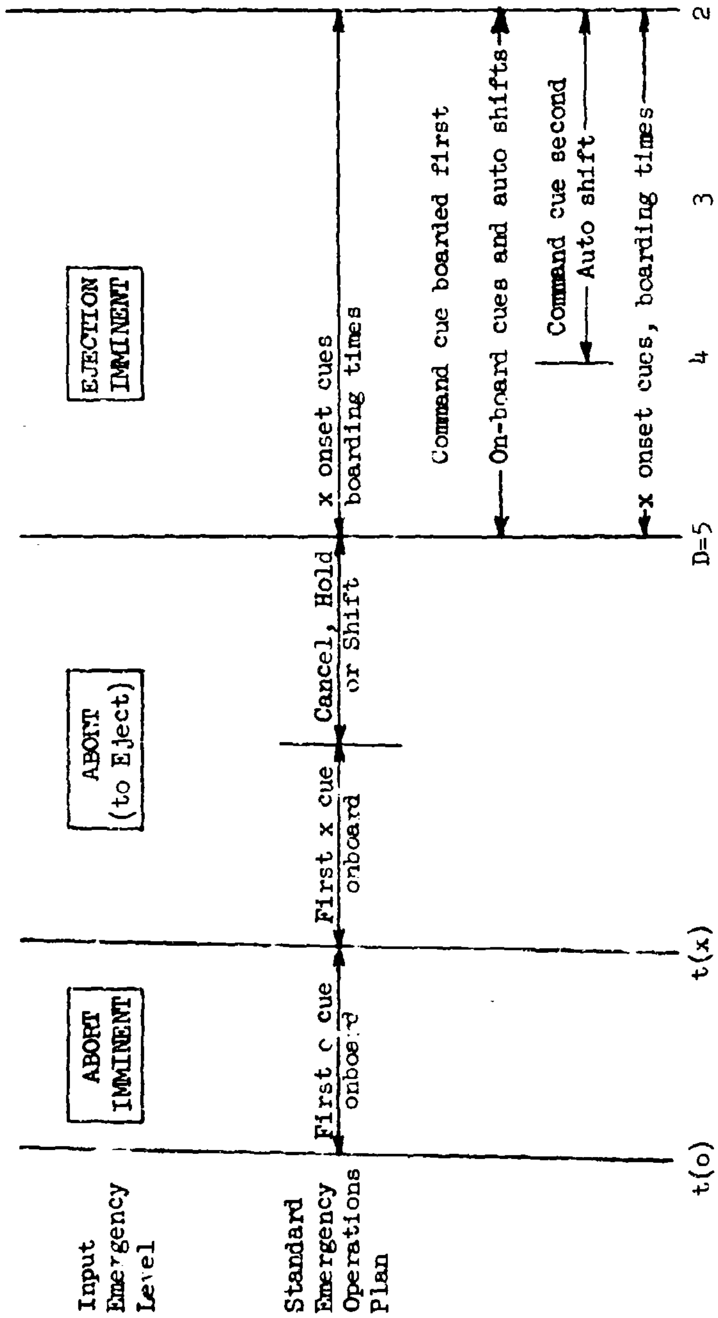


Figure 29 Sequence of Onboard Warning Events

It is significant at this point to summarize the information presented above on the use of sensed information. The unique problems with regard to the use of sensed information, introduced by the concept of two separated crew compartments, could have been answered on the simplest level by stating that the sensed information should be supplied to a warning and initiation system which would affect escape for two compartments rather than one or at least one in the event of escape system failure in the other. As such the problem reduces to a systems design problem.

In the present investigation the flexibility and decision making capability of man has been introduced into the system, necessitating a more detailed analysis in order to provide data for the establishment of jurisdiction. Man has been introduced, not as a replacement to an automatic escape system but in the combination of selective automatic control and parallel human effort.

With man in the system, control display equipment becomes significant. The existence of finite malfunction onset rates was used as the principle on which a concept of malfunction sequence monitoring was based and implemented in an onboard malfunction warning display, MWD. The MWD serves as both a passive malfunction and emergency status display and as an active command center for crew safety. As conceptually envisioned, similar, if not identical, displays would be located in each crew compartment. Since the MWD is a time sequenced display designed to rapidly orient the man to the problem, this arrangement permits the maximum use of the man in the plural compartment problem. Prior to staging, first stage performance will be monitored in both stages. During the staging maneuver, however, it will be necessary to supply information on fast onset malfunctions in each stage to each crew compartment. After completion of the staging maneuver, each stage will monitor only its own status.

The function of any crew escape device is the implementation of crew safety. Crew safety is a quantitative design parameter and requires design trade-offs in mission performance and expected mortality rates. The evaluation of a crew escape device introduces the notion of the value of a human life which is beyond the scope of the present general study. In this study, therefore, evaluation is limited to a qualitative evaluation and comparison. The parameters generally considered in an evaluation of escape devices are: 1) procedure complexity, 2) reliability; 3) weight; 4) effect on vehicle performance; 5) development time; and 6) cost.

In this section, the concern is with evaluation of warning and initiation devices which use sensed data. In addition to variations on the proposed manual/automatic system, there are the fully manual system and the fully automatic system. For evaluations to be practical, an attempt should be made to keep the mission objectives foremost in mind. Conventionally, we define mission objective as the aim of an operation. Mission objectives themselves may be said to vary widely - from simple to complicated, indicating their involvement of contemporary and advanced technologies. On these terms, the present advanced concept hypersonic aerospace mission is not a simple objective, but rather a complicated requirement mission.

Given the operational requirement as the advanced concept aerospace launch vehicles, the comparative evaluation presented in Table 8 has been prepared.

TABLE 8

EVALUATION AND COMPARISON OF ESCAPE INITIATION SYSTEMS

	Least →		→ Most
Procedural Complexity	All Auto →	Man/Auto →	All Man
Reliability	All Auto →	All Man →	Man/Auto
Weight	Man/Auto →	All Auto or	All Man
Effect on Vehicle Performance	All Man →	Man/Auto →	All Auto
Development Time	Man/Auto →	All Auto or	All Man
Cost	Man/Auto →	(All Man) →	All Auto

Complexity is used in the most general sense here; that is, complexity is that undefinable quality that makes for difficulty in solution, understanding and/or operation. Procedural Complexity is restricted here to mean inflight operating procedural complexity only, that is, checkout and preflight procedures have been excluded from the consideration. Such a restriction is viewed as properly oriented to the advanced concept vehicles under consideration.

Reliability is defined as the probability that the successfully-started system will complete operation for a specified time without failure, under stated conditions. The consideration of reliability of the escape system includes system opportunity to generate inadvertent escapes and to not sense real catastrophes. In simple missions with perfect recovery, the inadvertent escapes may be tolerable and the unsensed catastrophes unlikely. However, as the missions get more complicated (advanced) the attendant likelihood of unsensed catastrophes presents a considerable loss in life and, even with perfect recoveries, inadvertent escapes present mission inconsistencies in costs of failure and costs of repair or maintenance of worthwhile program objectives. The all automatic escape system as a system most typifies the foregoing considerations. It will lack the flexibility necessary to practically prevent both inadvertent escapes and unsensed catastrophes for advanced objectives of mission and crew safety.

Weight is taken in the ordinary sense, that is, in units of ponderable mass, the property of matter. In assessing the weight consideration, practically, the weight of man is excluded - he is going to make the trip regardless. The manual/automatic system would weigh less than the all automatic system since man would be

doing certain required functions which can be duplicated only by additional weight in an all automatic system. The manual/automatic system is said to weigh less than the all manual system because the all manual system is considered impracticable for the at-hand mission objective.

The term vehicle performance is taken as expressing vehicle capability. Vehicle capability is variously degraded by weights and sizes of the encumbering system and/or its necessary vehicle-borne adjuncts. The functional interference or interaction of mechanical sensors, tubing, wiring, mounting, etc., necessary to make a system all automatic deteriorates vehicle capability. Also, the irreducible probability of inadvertent interaction by inevitable adverse failure modes can be considered to degrade vehicle averaged capability.

Development Time is defined conventionally. It is that time required for operations analysis (conceptual), system design (definition), hardware design, hardware prototypes, test and evaluation as a function of product effectiveness, i.e., performance, reliability, maintainability, safety, etc. Here it has been plainly assumed that the all manual system is infeasible for first generation at-hand concept vehicles. Further, the all automatic simulation of man's flexibility is also unlikely in the time allocable to the development of a dual concept compromised system.

Cost. Cost is here defined in the practical terms of acquisition and ownership. Acquisition cost is the cost for development and production. Ownership cost is system lifetime cost of operating and maintaining the system, including the external cost of its failures. Considering reliabilities and development times as developed above, the all automatic system (because of ownership costs) is rated most costly. The manual/automatic system becomes least costly on the basis of both acquisition and ownership costs. The all manual system cost would turn out to be a lucky compromise indeed, if it should turn out somewhere in between.

Jurisdiction and Precedence. It has been previously indicated that one of the problems of escape initiation is jurisdiction. This is not unique to the concept of separated crew compartments in an advanced aerospace vehicle but is made more complex by this situation.

Jurisdiction is defined as the lawful right to hear and determine a cause or causes. Accordingly, precedence is proposed to give jurisdiction an operational quality. Wherever more than one abort right or authority is set forth, precedence establishes the conditional jurisdiction, priority or order.

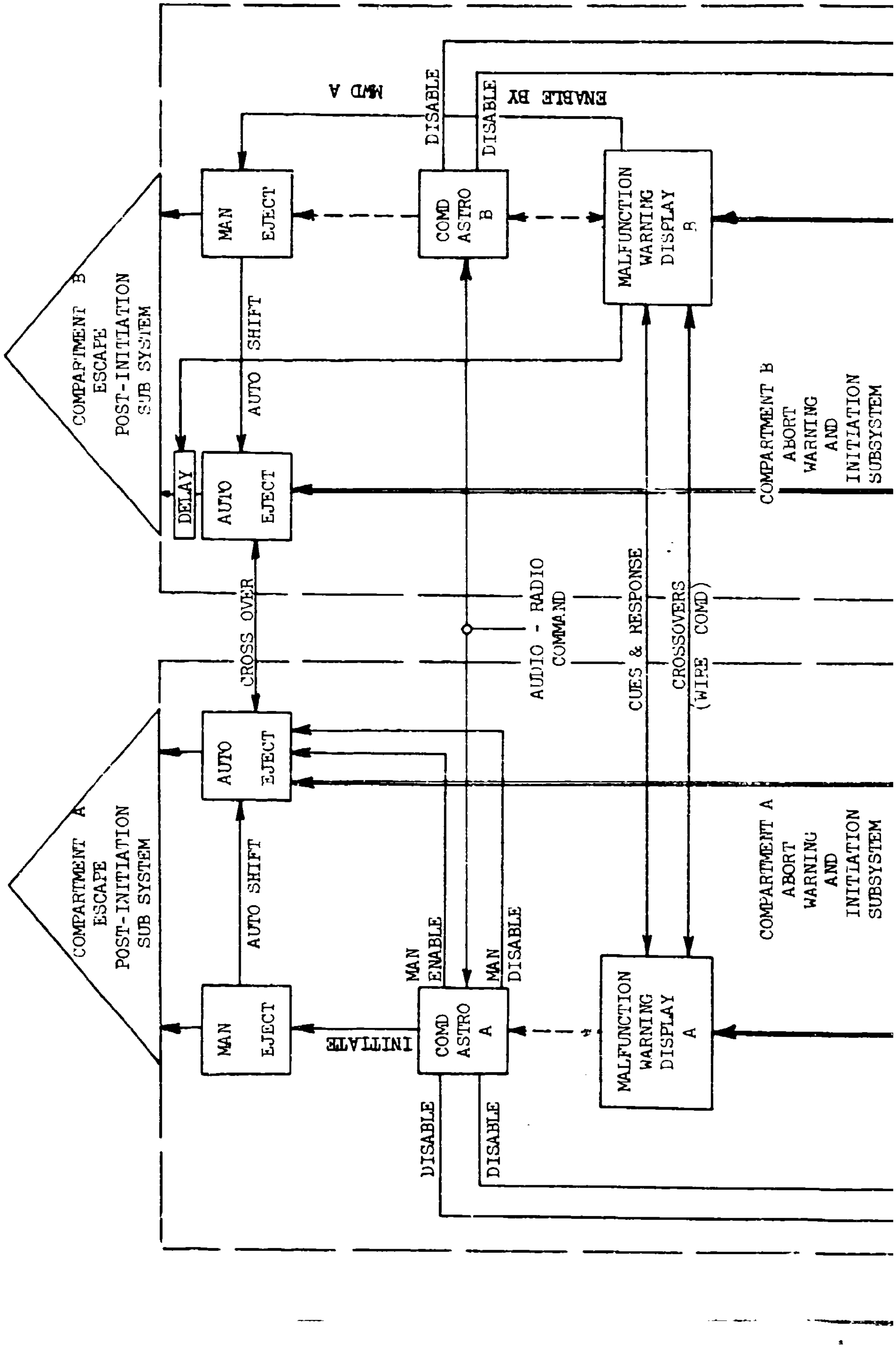
Figure 30 presents the general premises of the proposed jurisdictional and precedence concept. The likely absolute and conditional abort command posts are identified in the thus far developed manned vehicle surrounding, that is, with respect to the information in the Venn diagram of possible command posts presented in Figure 20, and added likely mission events for a hypothetical VTOHL vehicle. A VTOHL vehicle was selected for presentation since it is envisioned to have more possible command posts than an HTOL vehicle. An HTOL vehicle can be likened to an airplane in that it would be maneuverable from takeoff and would most likely be under manual control. Consequently the number of off-board or ground command posts would be smaller and their period of control shorter.

Based on the definitions of jurisdiction and procedure given above, it is proposed that jurisdiction be conceptually equal in both crew compartments as indicated in Figure 31. This concept maximizes emergency flexibility and response. After vehicle escape system arming and prior to separation, however, the jurisdiction

	TYPICAL MISSION EVENT, ACTION:	ASD Operations Director	Real Time Recording Observers (O)	Technical Observers (Sighting) O(S)	Range Safety Officer (RSO)	Test Conductor (TC)	Vehicle Command Post	Senior Commander Other Compartment
1.	VTOHL Vehicle, Counting (Pre-board)	-	-	2/1	-	LL 1	-	-
2.	Both Crews Boarding	2	-	3/1	-	LL 1	-	-
3.	Both Crews on Stations	2	4/(1,2)	3/1	-	LL 1	-	-
4.	Both Capsules Squib Bus Arm Complete	2/1	4/(1,2)	3/1	-	LL/RAD 1	MAN REQ	MAN REQ
5.	Test Conductor Abort Arm Complete	2/1	4(1,2)	3/1	-	LL/RAD 1	MAN 2	MAN 3/2
6.	Vehicle Auto Escape Ready Conditional	2/1	4/(1,2)	3/1	-	LL/RAD 1	MAN 2	MAN 3/2
7.	Vehicle Auto Release Pre-Arm Complete	2/1	4/(1,2)	3/1	-	LL/RAD 1	MAN 2	MAN 3/2
8.	Vehicle First Stage Engines Up	2/1	4/(1,2)	3/1	-	LL/RAD 1	MAN 2	3/2
9.	Vehicle Auto Release Complete (Auto Escape Arm)	3/1	4/(3,2)	2/1	-	LL/RAD 1	MAN 2	3/2
10.	Lift-Off $\mp$ (R) Sec. Complete	4/3	6/4	5/4	RAD 3	(LL)RAD 2	AUTO (MAN)	2/1
11.	Pitchover $\mp$ (P) Sec.	RAD 2	4/2	3/2	RAD 3	RAD -	MAN 1	2/1
12.	Staging $\mp$ (S) Sec.	RAD 2	4/2	3/2	RAD 3	RAD -	MAN 1	2/1
13.	(Separation)	RAD 2	3/2	4/2	RAD 3	RAD -	MAN 1	-

LL = Landline; RAD = Radio; MAN = Manual; AUTO = Automatic; REQ = Request
Single number entries denote proposed absolute jurisdictions.
Multiple numbered entries denote proposed conditional jurisdictions.
Only single numbers and denominators denote precedence in common, e.g.,
3/(2,1) means: This jurisdiction contingent on the absolute jurisdictions designated in this row as 2 or 1.

Fig. 30 Preliminary Guidelines of Jurisdiction and Precedence for Abort Command of Separate Crew Compartment Space Vehicles


COMPARTMENT B
ESCAPE
POST-INITIATION
SUB SYSTEM
MAN EJECT
AUTO EJECT
DELAY
COMD ASTRO B
MALFUNCTION WARNING DISPLAY B
DISABLE
DISABLE
ENABLE BY MWD A
AUTO SHIFT
CROSS OVER
AUDIO - RADIO COMMAND
CUES & RESPONSE
CROSSOVERS (WIRE COMD)
COMPARTMENT B
ABORT
WARNING
AND
INITIATION
SUBSYSTEM
COMPARTMENT A
ESCAPE
POST-INITIATION
SUB SYSTEM
AUTO EJECT
AUTO SHIFT
MAN EJECT
INITIATE
COMD ASTRO A
MAN ENABLE
MAN DISABLE
DISABLE
DISABLE
MALFUNCTION WARNING DISPLAY A
COMPARTMENT A
ABORT
WARNING
AND
INITIATION
SUBSYSTEM

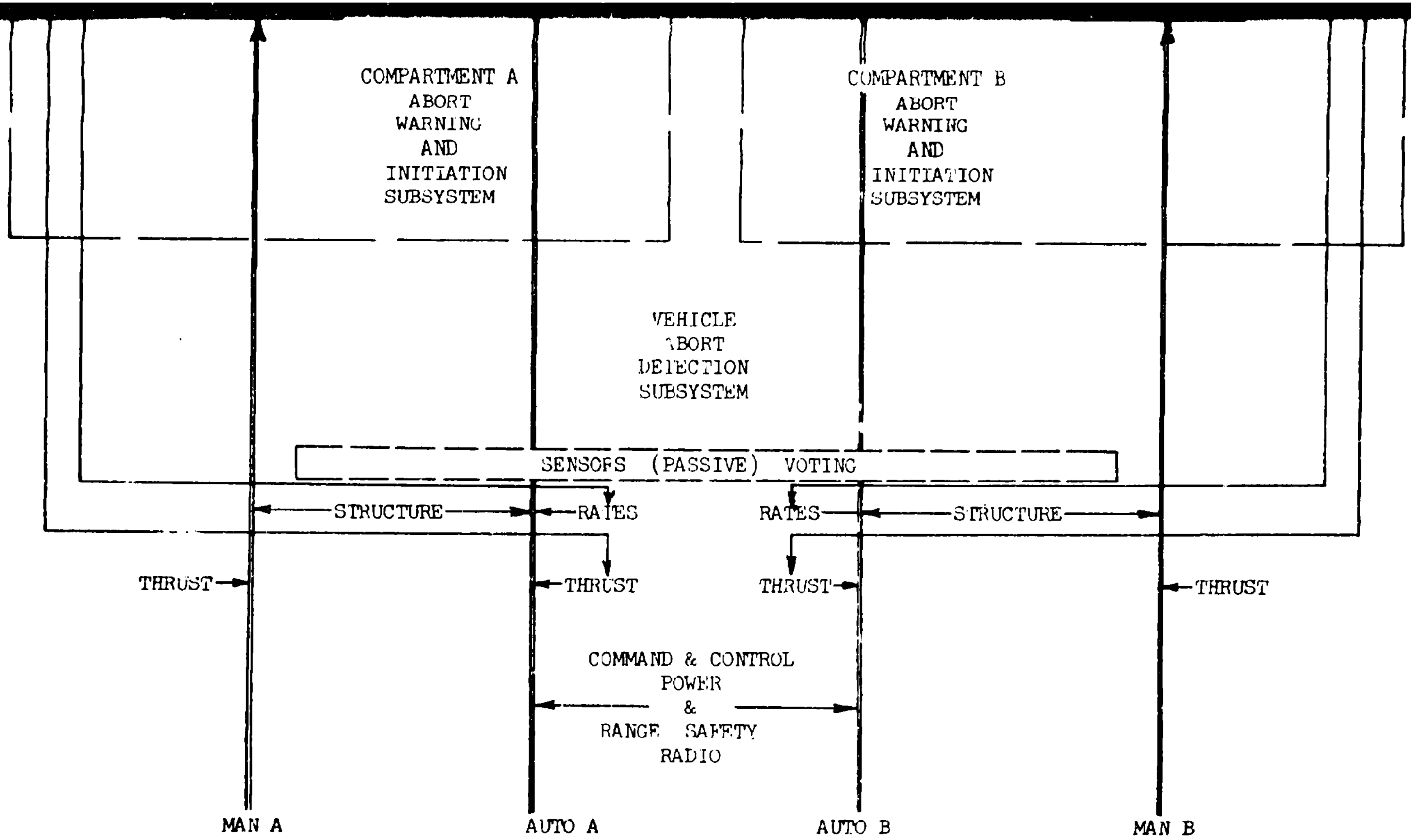


Figure 31 Two Compartment Vehicle Abort Jurisdictional Relationships

of the subordinate compartment, B, is operationally conditional and subject to precedence vested exclusively in the mission designated vehicle commander, A. Since it has been proposed that similar warning systems, MWD, be located in each compartment, with the second stage monitoring first stage performance prior to stage separation, the designated commander for any given mission could be either in the first or second stage.

Figure 32 presents some details regarding emergency level, display information, and escape initiation. Figure 32 develops the circumstances of precedence in the following manner.

The notes shown on the figure set forth the definitions of the key time parameters used. Time is real time measured from a considered point in time, t, prior to or at the time of the escape initiation act, $t(\Delta)$. Note A defines τ and $\hat{\tau}$ variables which denote the time interval between a considered point in time and escape initiation. Note B identifies the available decision window as D, where $\hat{\tau} > 0$. Note C designates the time of the escape initiation act as $t(\Delta)$, where $t(\Delta)$ may either be a manual or automatic initiation. Note D sets forth t(AUTO) as the time of automatic escape initiation, where t(AUTO) will be equal to or less than $t(D = 0)$. Note E designates the time of manual escape initiation as t(MAN) where t(MAN) will be equal to or less than t(AUTO).

The left side of Figure 32 lists the possible "responsible operations" of the proposed concept in terms of hazard information evaluation and initiating command post. The hazard information listing is time ordered, i.e., entries begin with the smallest value of $\hat{\tau}$ (representing the most urgent emergencies) and develop downward to times equal to t(o), recognized as the time of the first indication of a least urgent emergency level malfunction. The column entitled EMERGENCY LEVEL indicates the associated designations as developed previously. The adjacent column to the right entitled INITIATING CP merely designates the command post, (CP), initiating the emergency level as being on board or off board.

The remaining section of Figure 32 indicates the conceived on-board emergency-oriented particulars. All the entries except the first two under the column entitled "OPTION OPEN" are identifiable to the commander's keyboard on his malfunction warning display (MWD). (The exceptions, NONE and MANUAL EJECT, are prior understood options available). Clearly, there is no option open to the commander on item one of Figure 32 and in item 2, the commander's left hand will be off the board, grasping the eject handle.

Under the column in Figure 32 entitled "TYPE", either one of two entries "COMD" or "OPNS" is listed. The entry "COMD" (Command), is identifiable to the MWD left, and the entry "OPNS", (Operations), to the MWD right, consistent with all notions developed above. The adjacent column to the left, entitled "WINDOW" lists the on-board decision window count intervals identifiable to the MWD, center. The adjacent column on the right indicates the options which are open to the commander.

During ABORTS, and ABORT IMMINENTS, the commander will find it necessary to acknowledge and direct time and attention consuming options and exercises. For unknown rate or fast degenerating ABORTS, inter-compartment options should most likely involve acknowledgements, enables, responses and disables by WIRE COMMAND as noted in Figure 31, rather than the relatively more cumbersome audio command address. On the other hand, during the more slowly degenerating ABORTS, or ABORT IMMINENTS, the AUDIO COMMD option will most likely be required to handle to situation complexities of problem address and detail length.

RESPONSIBLE OPERATIONS				ON - BOARD EMERGENCY ORIENTED PARTICULARS						
				DISPLAY INFORMATION			OPTION		ESCAPE INITIATION	
ITEM	HAZARD INFO. EVALUATION	EMERGENCY LEVEL	INITIATING CP	WINDOW	TYPE	OPTION OPEN	INPUT	INITIATOR	MODE	PRECEDENCE
1	$0 < \hat{\tau} \leq 2$	EJECT	Off-board	D = 0	Comd.	(None)	-	-	Auto	Absolute
2	"	"	On-board	$0 < D < 2$	Opns.	(Man Eject)	Cue	Comdr.	Man	Comdr. Over D > 0
3	$2 < \hat{\tau} \leq 5$	EJECTION IMMINENT	"	$2 < D \leq 5$	Comd. / Opns.	"	"	"	"	"
4	$\hat{\tau} \geq 5$	"	Off-board	D = 5	Comd.	"	"	"	"	"
5	$\hat{\tau} > 5$ and $t \geq t\ (x)$	ABORT (TO EJECT)	Off-board	D > 5	Comd.	REQUEST SOP	"	"	"	Comdr. Over Wire Comd. PSRO Options
6	"	"	On-board	"	Opns.	"	"	"	"	"
7	"	"	"	"	"	REQUEST CUE	"	"	"	"
8	"	"	"	"	"	SHARE BOGEY	"	"	"	"
9	"	"	"	"	"	AUDIO COMD.	"	"	"	Comdr. Over Audio Comd. PSRO Options
10	$t(o) \leq t < t(x)$	ABORT IMMINENT	On-board	"	Opns. / Comd.	DETAIL CANCELLED	"	"	"	Comdr. Over Directed PSRO Details
11	"	"	"	"	"	AUDIO DETAIL	"	"	"	"
12	"	"	"	"	"	EXERCISE CANCELLED	"	"	"	Comdr. Over Directed Exercises
13	"	"	Off-board	"	Comd.	"	"	"	"	Comdr. Over Off-board Abort Imminents
14	"	"	On-board	"	Opns. / Comd.	COMD. EXERCISE START	"	"	"	Comdr. Over Directed Exercises

						CANCELLED				Directed Exercises
13	"	"	Off-board	"	Comd.	"	"	"	"	Comdr. Over Off-board Abort Imminents
14	"	"	On-board	"	Opns. / Comd.	COMD. EXERCISE START	"	"	"	Comdr. Over Directed Exercises
15	"	"	Off-board	"	Comd.	COMD. EXERCISE STANDBY	"	"	"	Comdr. Over Off-board Abort Imminents

NOTES:

A $\hat{\tau}$ = The best available estimate of τ; where
τ = $t(\overline{S}) - \Delta t$,
where
Δt is the absolute minimum time interval required to effect the escape act, and $t(\overline{S})$ is the waiting time to expected safety defined in Figure 23.

B D = The available decision window;
D = $\hat{\tau} > 01$.

C $t(\Delta)$ = The time of automatic escape initiation;

D $t(AUTO)$ = The time of automatic escape initiation;
$t(AUTO) \leq t(D = 0)$.

E $t(MAN)$ = The time of manual escape initiation;
$t(MAN) \leq t(AUTO)$

FIGURE 32 - Details of Emergency Events, Operations and Initiation Precedence Subsequent to Arming Escape System

2

During ABORTS and ABORT IMMINENTS, the spatial orientation and flow of commander visual and left hand manual action with respect to the MWD is conceptually generalized by the diagram in Figure 33.

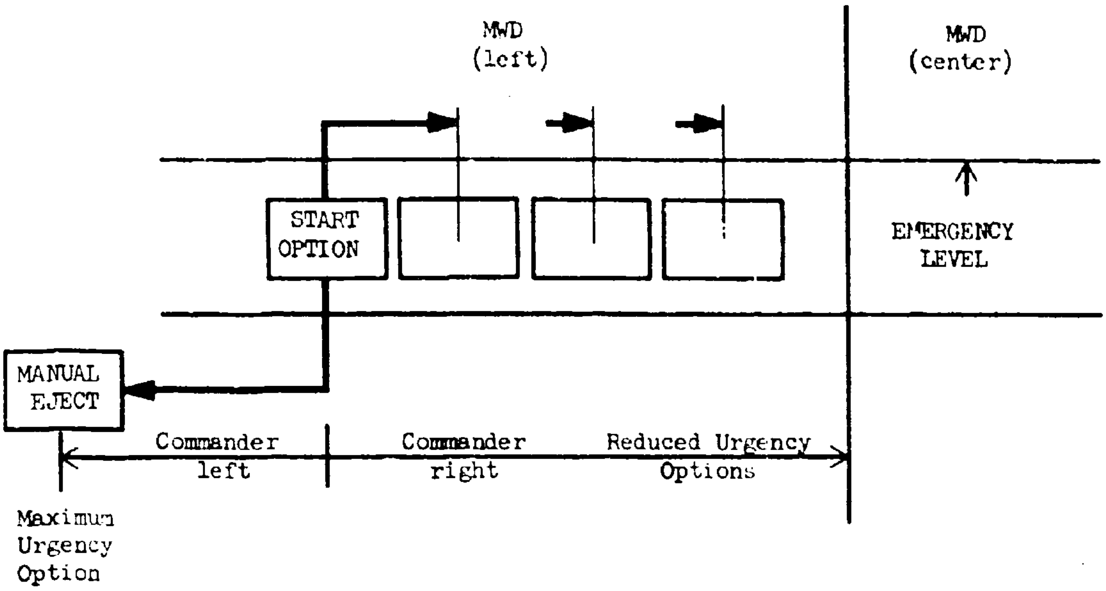


FIGURE 33 - GENERAL CONCEPT OF COMMANDER VISUAL AND LEFT HAND MOTION WITH RESPECT TO MWD

The ABORT (to EJECT) level REQUEST SOP option is proposed for commander use in unknown rate or fast degenerating ABORTS. The commander requests the response compartment to furnish by wire a SEAT OF PANTS emergency level decision (i.e., a decision in less than two seconds under conditions of no advance cue).

The commander may, in some related instances of time and peculiar urgency, direct the "REQUEST CUE" option. Here the response compartment has two seconds to flash his latest received most important cue. The flashing would appear on the commander's MWD, right, or operations malfunction and sequence "tree" for the duration of the option. The commander may, in some follow-on instances to the foregoing or in cases of peculiar urgency, direct the "SHARE BOGEY" option. Here response compartment decisions for EJECTION IMMINENTS or EJECTS would be enabled as having commander authority for the duration of the option.

The ABORT IMMINENT level COMD EXERCISE STANDBY option is announced via AUDIO (RF) command channel by the commander upon receiving an off-board ABORT IMMINENT when his immediate attention is required by some other more important on-board task. In appropriate follow-on instances to the foregoing the COMD EXERCISE START option is announced (via the AUDIO (RF) command channel) and indicated by the commander's subsequent operation of the COMD EXERCISE START indicator button. Any subsequent EXERCISE CANCELLED, AUDIO DETAIL or DETAIL CANCELLED option is announced via the AUDIO (RF) command channel and indicated by the commander's operation of the appropriate indicator button. Acknowledgment of these options by the

responding compartment would be made, e.g., responder pushes appropriate button in his compartment causing a flashing of the corresponding button on the commander's MWD. Upon receipt of acknowledgment of a cancellation the commander can then clear the option channels for future use.

In the remaining section of Figure 32 we observe that the OPTION INITIATOR except for item 1, is always the commander, COMDR, and that his escape initiation act is always MANUAL. In the right-most column entitled "PRECEDENCE" we note that any WIRE or AUDIO COMD or Problem/Skill/Response/Oriented (PSRO) initiation-terminating acts must be created by an option of the commander, and as such remain for the duration of the option as subject to commander absolute manual precedence or override.

Since the staging maneuver introduces certain sequencing peculiarities which will be discussed in the next section, it is proposed that the auto eject system have precedence during this maneuver.

Summarizing the jurisdiction and precedence discussion it has been shown that both vehicle and ground command posts have jurisdiction, defined as authority, and therefore it was necessary to establish precedence or priority of jurisdiction.

In general, as the vehicle becomes airborne the precedence goes from ground command posts to the preselected on-board mission commander. The other on-board commander has precedence only at the option of the mission commander. Manual precedence in any given emergency status is conditional on the availability of a decision window. In the absence of a decision window, auto eject has absolute precedence.

The order of precedence between the on-board commanders could be established either by a "gentlemens' agreement", (both capsules would be armed and eject would occur if the manual eject button were pushed in either stage), or could be absolute (manual eject circuit of secondary compartment must be activated by mission commander). There are advantages and disadvantages associated with each possibility, however, it is believed that the "gentlemens' agreement" approach would be the most satisfactory especially in terms of crew morale.

6.2 SEPARATION

Following malfunction detection and initiation of the escape sequence the escape capsules must separate from the aerospace vehicle and attain a safe environment from which a recovery can be made. The act of separation actually encompasses two different actions. The first act is the separation of the physical connections between the primary vehicle and the escape capsules. The second act is the movement of the capsules from the primary flight vehicle to a safe environment.

The first act of separation, that of severance of connections, is a mechanical act occurring at the interface and hence is not influenced by the number of escape capsules. Therefore, the physical disconnect phase of separation was not considered in the present study and only the separation phase from disconnect to safe environment was investigated. This definition of separation reduces the separation phase to strictly a flight dynamics problem.

The basic problem in the separation phase is insuring that the escape vehicle is placed in a safe flight environment without exceeding any human tolerance or vehicle limits. This safe environment is defined as one in which the capsule has

sufficient clearance between itself and the other escape vehicle, the primary flight vehicle and any dangerous blast wave from an explosion. In addition to the establishment of basic capsule vehicle separation criteria, applicable to any aerospace vehicle escape capsule, it was the objective of this investigation phase to establish criteria in regard to crew compartment location, delay time between separation of each capsule, thrust magnitude and direction applicable to aerospace vehicles having two separated crew compartments.

Separation characteristics were investigated at the critical areas defined in Section 4.4, i.e., zero zero, high dynamic pressure and high Mach number.

In order to conduct flight dynamics studies it is necessary to have information on the aerodynamic and mass properties of the escape capsules. Since this was not a design study, it was necessary to assume certain characteristics. Both ballistic and lifting-type capsules were considered since the type of escape capsule could affect the criteria for crew compartment location and separation requirements. The capsule models used were those presented in Figures 17 and 18 and discussed in Section 5. Although these capsules are adapted from crew escape studies for a one-man crew, the configurations are applicable to the present investigation since the trajectory performance is a function of such non-dimensional parameters as thrust to weight and wing loading.

The capsules shown in Figures 17 and 18 are nose capsules. As mentioned in Section 5, there is another capsule type called the pod capsule. Pod capsules are located aft of the nose and can also be either lifting or ballistic types. Pod capsule performance differs from nose capsule performance primarily in that pod capsules are more influenced by aerodynamic interference effects in the initial separation phase. Since these interference effects depend primarily on the specific geometric configurations, a quantitative evaluation of these effects is beyond the scope of this study. In a specific design study these effects would have to be considered, however, for the present study it can be assumed that the separation trajectory results obtained with the nose capsules are also applicable to pod-type capsules.

In the separation investigation the following aspects were considered:

1. Separation between a capsule and the aerospace vehicle

2. Separation between two capsules

3. Explosion separation requirements

4. Crew compartment location criteria

6.2.1 CAPSULE-VEHICLE SEPARATION. The first aspect of separation considered was the separation characteristics between a capsule and a vehicle. This information is applicable directly to single crew compartment vehicles but is also applicable to the individual capsule separation characteristics of an aerospace vehicle having two crew escape capsules. The effect of the following parameters on separation characteristics were investigated:

1. Separation rocket thrust magnitude and direction

2. Initial flight path angle and angle of attack

3. Initial velocity and altitude

6.2.1.1 Techniques. The separation trajectory characteristics have been obtained using a three degree of freedom IBM 7090 digital computer trajectory program. The program includes the vehicle dynamics in the pitch plane and has the following significant features:

1. Separate capsule and control surface aerodynamic data as a function of Mach number and angle of attack.

2. Escape rocket thrust as a function of time including a build-up and decay.

3. Autopilot to provide damping through the use of either reaction controls or aerodynamic surfaces.

4. Variable mass, inertias and c.g. position as a function of expended fuel weight.

5. Thrust as a function of time with a specific impulse of 225 seconds.

6. Separation distance from the primary vehicle is obtained by assuming the primary vehicle continues along its initial flight path at its initial velocity.

The outputs of the program are time histories of position, velocity, angles, and load factor.

6.2.1.2 Aerodynamic Data. The more significant aerodynamic lift, drag, and moment characteristics used in the trajectory program are presented in Figures 34 and 35 for the ballistic capsule and lifting body capsule respectively.

6.2.1.3 Separation Distance Characteristics

On the Pad. On the pad escape determines the maximum thrust values allowable from human tolerance considerations since at this condition there are no relieving aerodynamic forces initially, (the same reasoning would apply to orbital escape). The rocket thrust must be inclined to the centerline of the vehicle for both VTOHL and HTOL vehicles. In the VTOHL the inclination is required to achieve lateral displacement while in the HTOL it is required to achieve sufficient altitude to execute a parachute recovery.

Figures 36 and 37 present the ballistic body resultant separation distance as a function of thrust loading (thrust/weight) and thrust angle, (measured from the centerline) for horizontal and vertical take-off respectively at an initial velocity of zero. As would be expected, the higher thrust loadings result in the larger separation distance. The results show that decreasing the thrust angle increases the separation distance. This occurs since lower thrust angles yield lower initial angles of attack and hence lower drag.

Figures 38 through 41 present ballistic body separation distance as a function of thrust loading, thrust angle and burning time for both horizontal and vertical take-off vehicles. Extending the burning time of the rockets result in larger separation distances between the escape capsule and the primary flight vehicle.

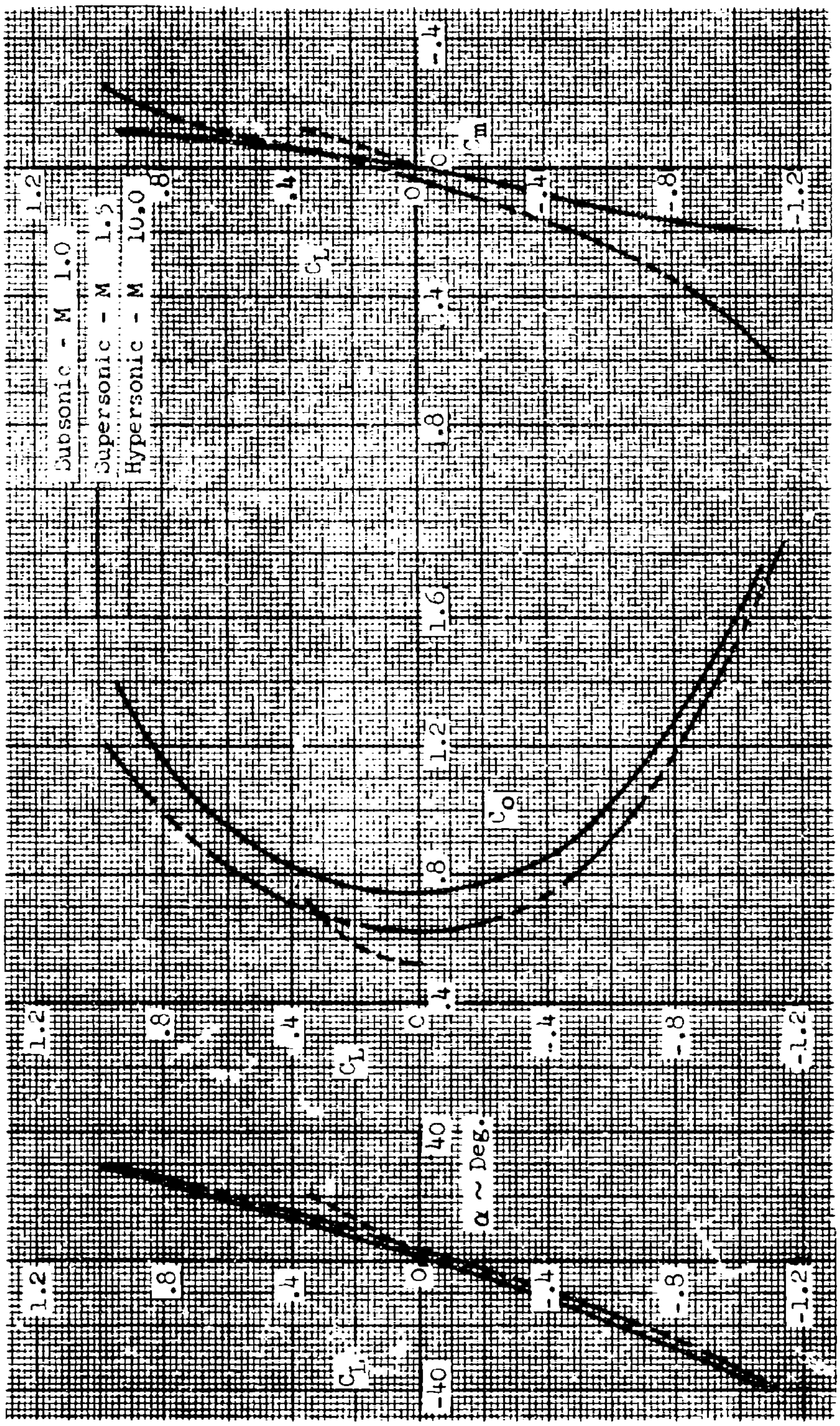


FIGURE 34 - BALLISTIC BODY AERODYNAMIC DATA

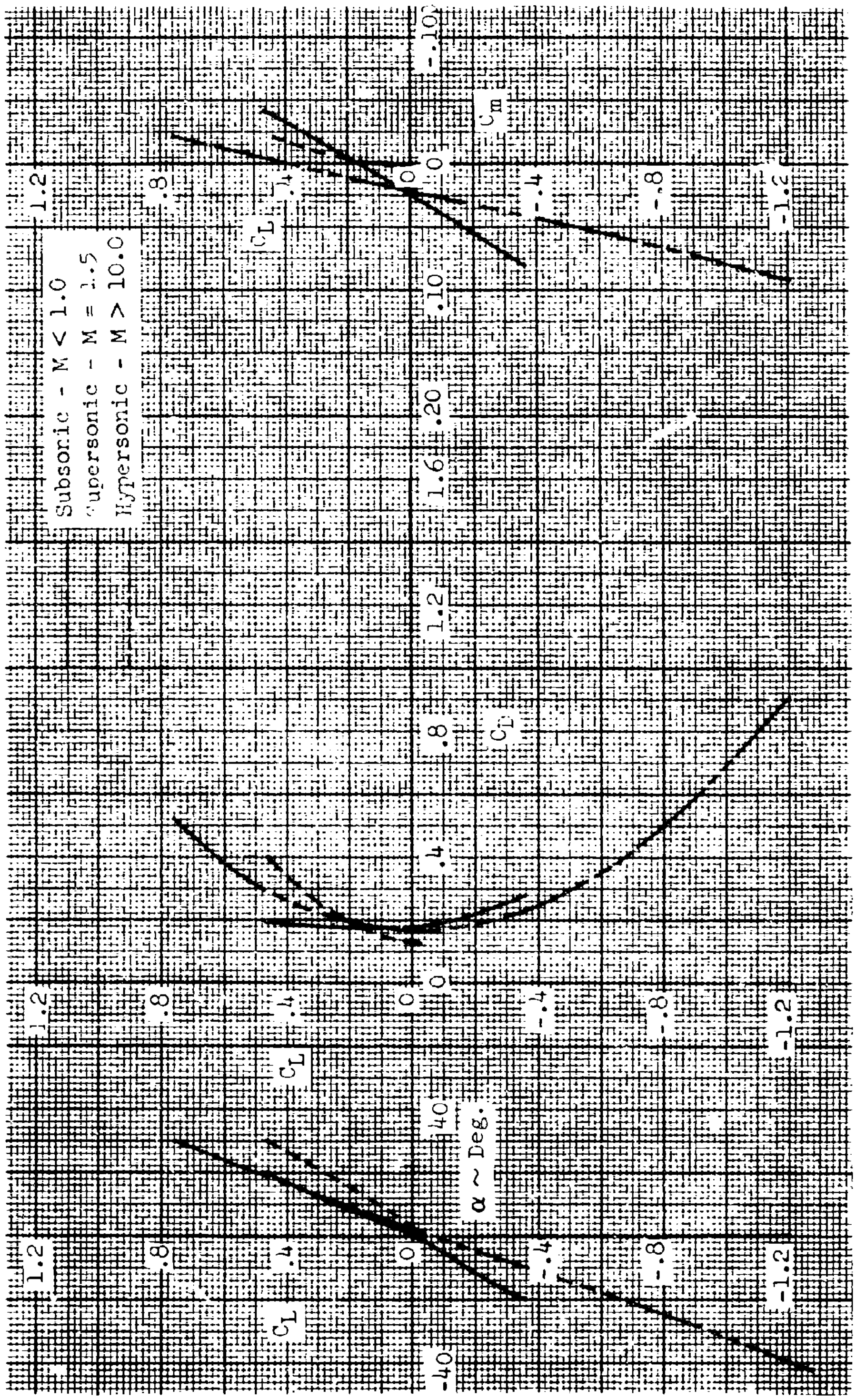


FIGURE 35 - Lifting Body Aerodynamic Data

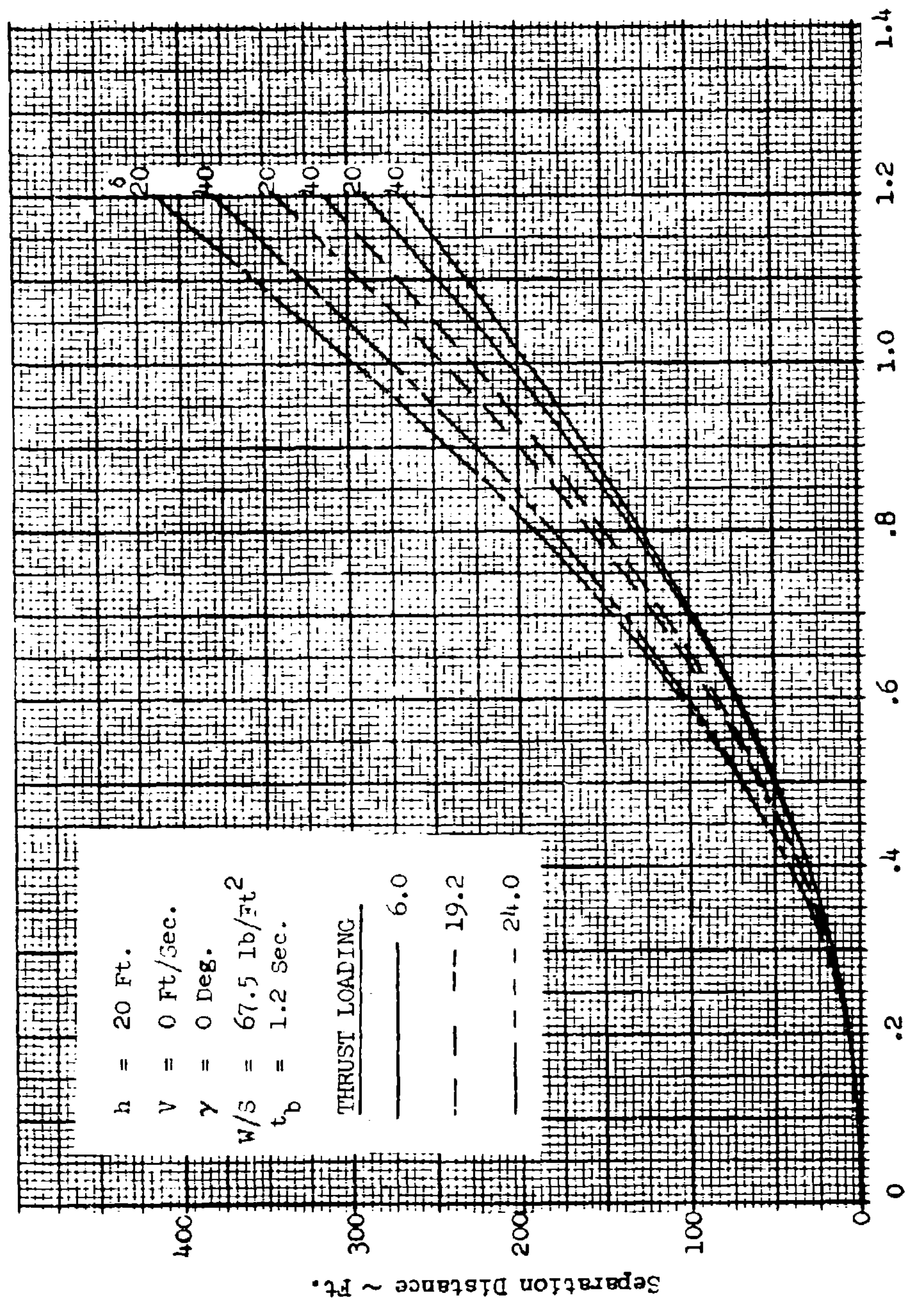


Fig. 36 On The Pad Separation Distance - Ballistic Body - Horizontal Take-Off
Effect of Thrust, Magnitude and Direction

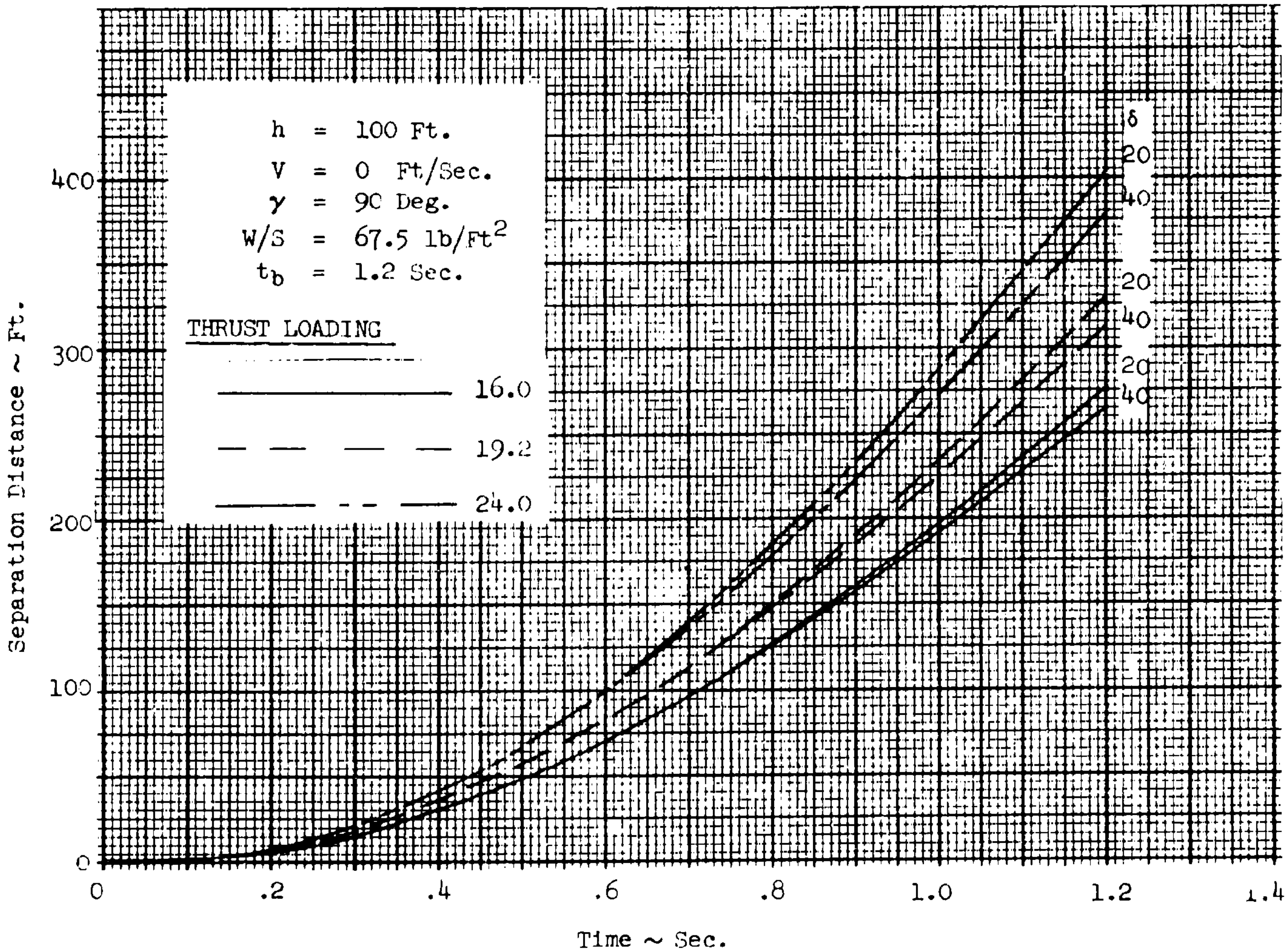


FIGURE 37 - On The Pad Separation Distance - Ballistic Body - Vertical Take-Off
Effect of Thrust Magnitude and Direction

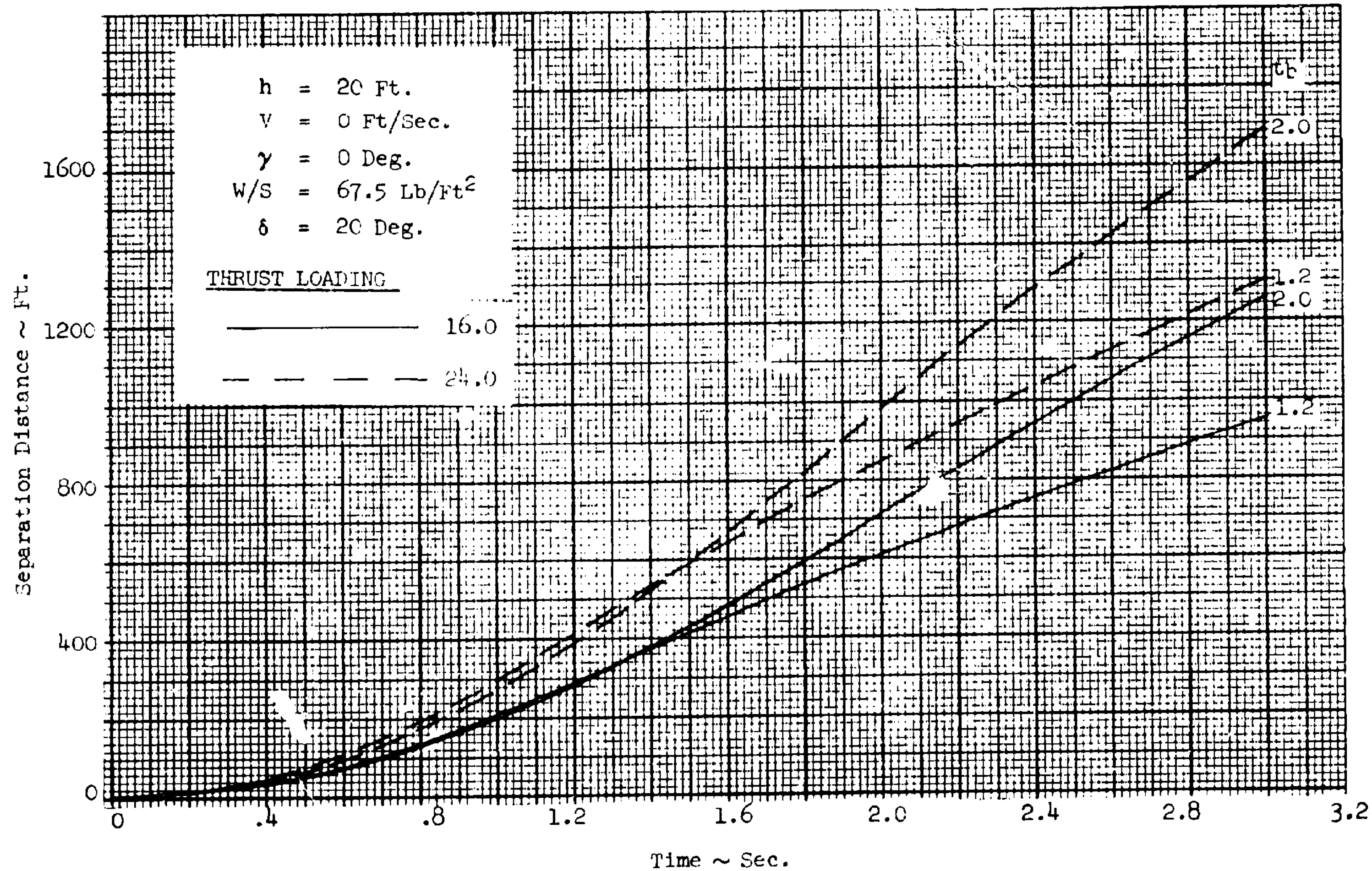


FIGURE 38 - On The Pad Separation Distance. Ballistic Body - Horizontal Take-Off
Effect of Rocket Burning Time

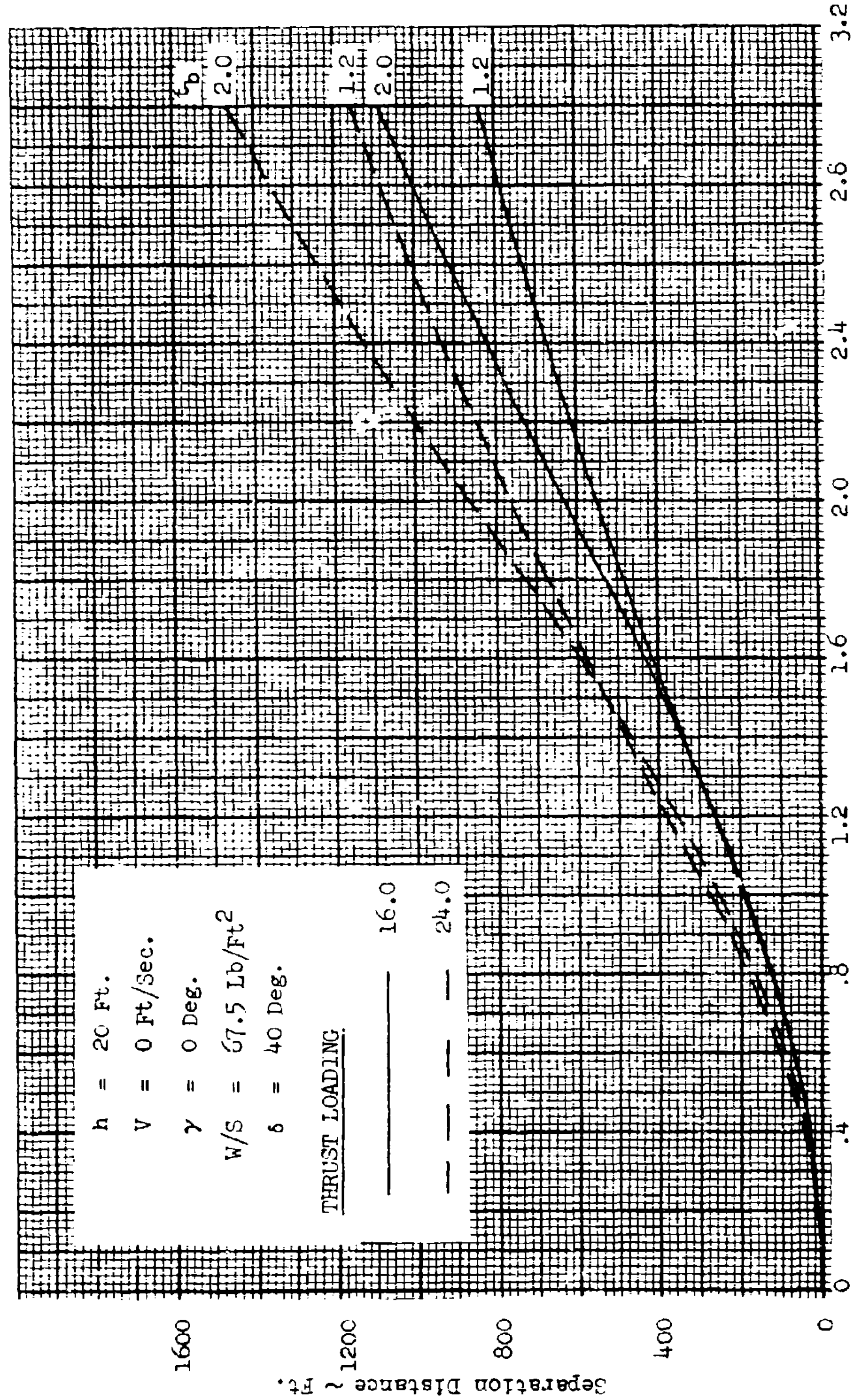


FIGURE 39 - On The Pad Separation Distance - Ballistic Body - Horizontal Take-off Effect of Rocket Burning Time

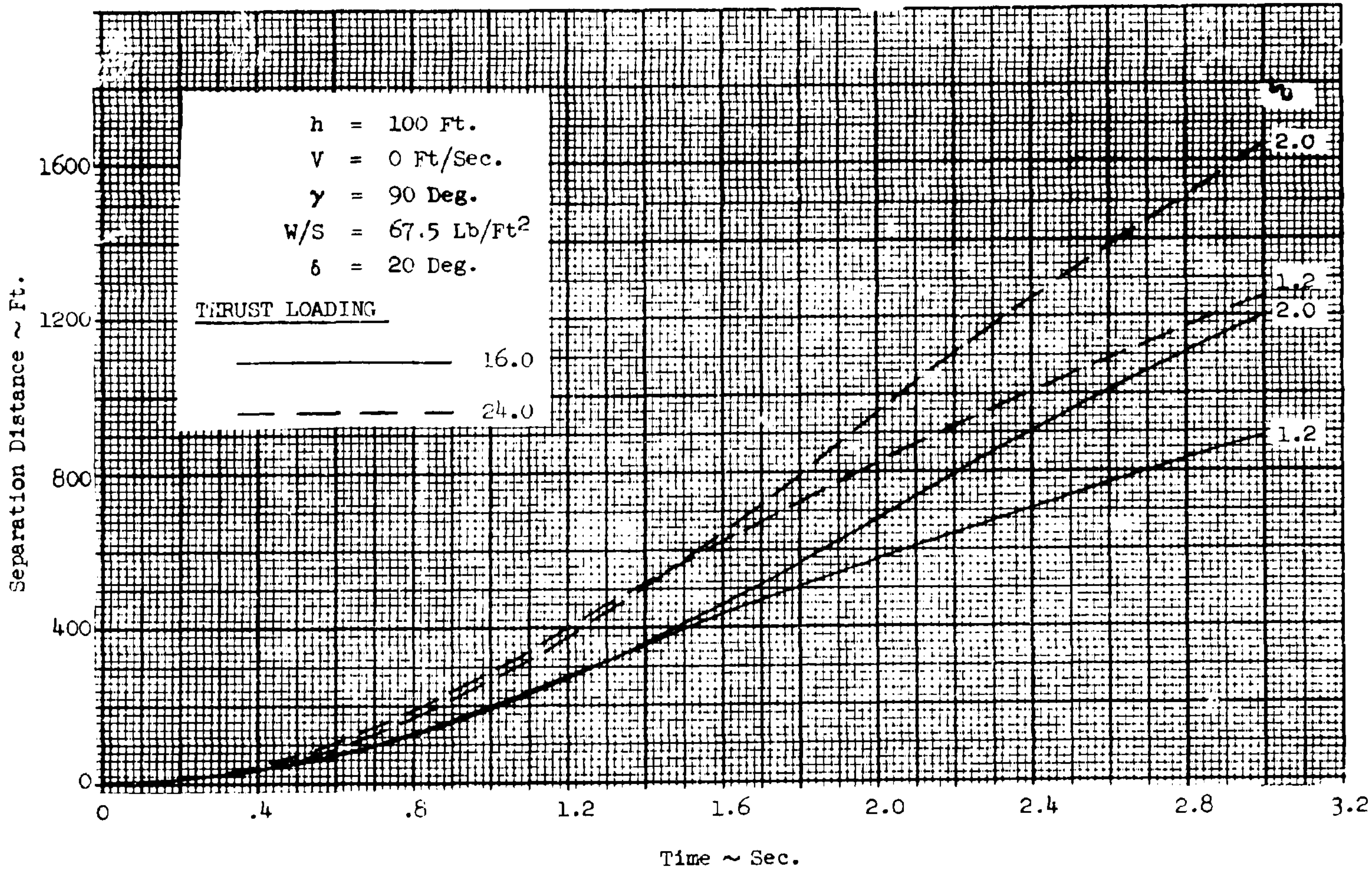


FIGURE 40 - On The Pad Separation Distance - Ballistic Body - Vertical Take-off
Effect of Rocket Burning Time

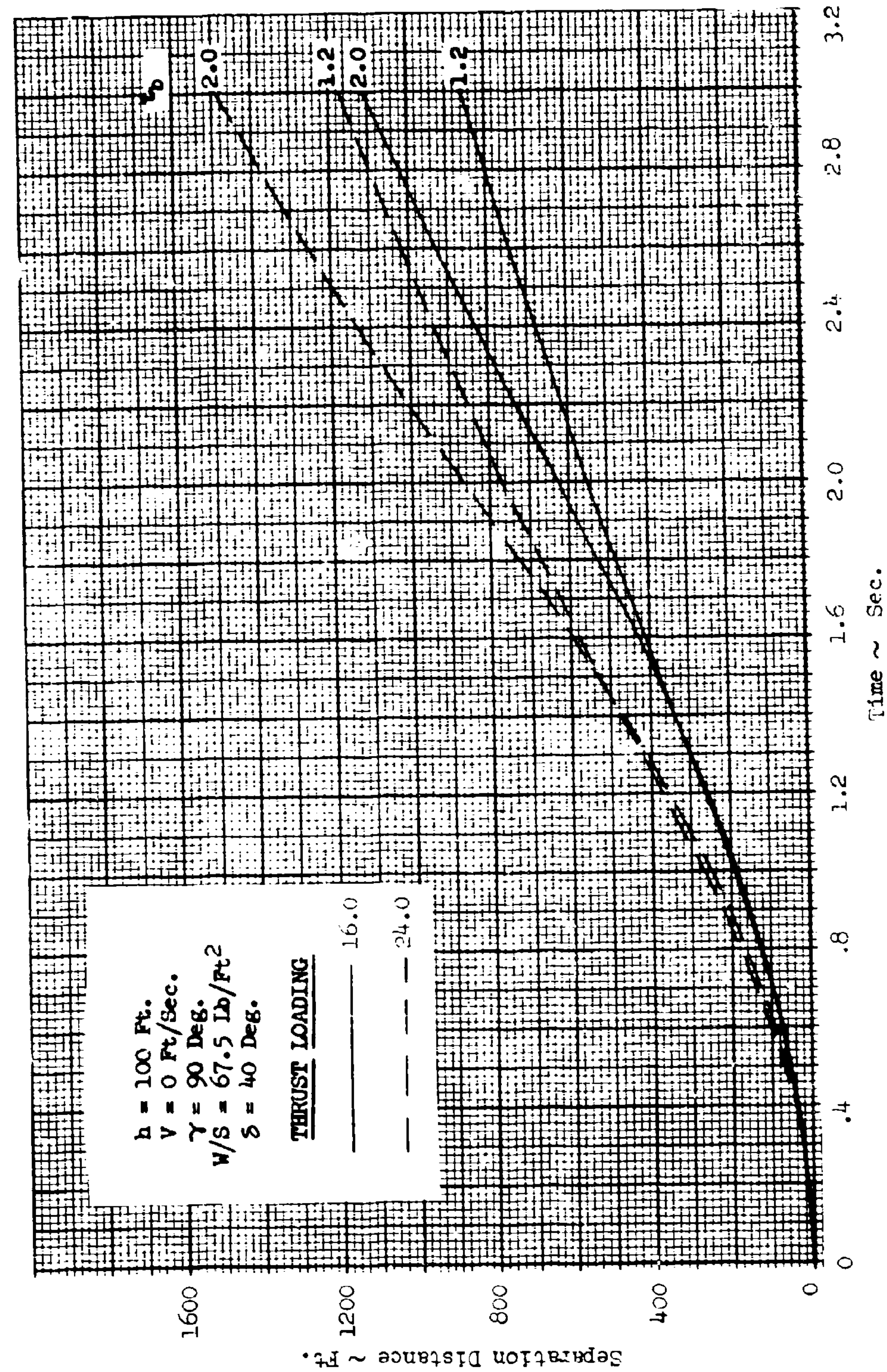


FIGURE 41 - On The Pad Separation Distance - Ballistic Body - Vertical Take-off
Effect of Rocket Burning Time

The separation distance characteristics for the lifting body capsule in both the vertical and horizontal take-off positions are presented in Figures 42 through 47 as a function of the parameters of thrust loading, thrust angle and burn time. The effect of variations of these parameters on the lifting body separation performance were similar to the trends established for the ballistic body.

Lower values of thrust loading were used for the lifting body than for the ballistic body since the ballistic body would have higher drag at the maximum dynamic pressure condition necessitating higher separation forces.

High Dynamic Pressure. Maximum dynamic pressure escape determines the minimum thrust values required to achieve separation since at this condition the air loads opposing separation are at their maximum. The high dynamic pressure separation performance characteristics were investigated considering the range of parameter variations shown in Table 9.

Table 9 High Dynamic Pressure Separation - Parameter Range

	Ballistic Body	Lifting Body
Altitude - ft.	27,000-80,000	27,000-40,000
Velocity - ft/sec.	1800	1800
Flight path angle - degrees	5 - 60	5 - 45
Thrust loading -	12.8 - 24	8 - 14
Thrust angle - degrees	20 - 40	20 - 40
Wing loading - lbs/sq. ft.	54 - 81	22.7 - 34.1
Nominal rocket burn time - seconds	1.0 - 2.0	1.0 - 2.0

The effect of flight path angle at a given velocity-altitude condition was investigated for the ballistic body and found to be insignificant and therefore was not considered in the lifting body study.

The separation distance characteristics as a function of time for the ballistic body at high dynamic pressure are presented in Figures 48 through 54. The effect of thrust loading and direction on separation distance is presented in Figures 48, 49 and 50 for altitudes of 27,000, 40,000 and 80,000 ft. respectively. The results show that separation distance characteristics improve with increasing altitude at constant velocity.

The effect of wing loading on separation distance at various thrust loadings is shown in Figures 51 and 52 for altitudes of 27,000 ft. and 40,000 ft. respectively. As shown, the separation distance increases with wing loading except at 27,000 ft. altitude and a thrust loading of 19.2, where a wing loading of 54 is shown to be better than 67.5. The data at these initial conditions is unrealistic since the thrust is not sufficient to overcome the drag and the separation distance indicated is merely a result of the capsule decelerating from a constant velocity primary flight vehicle. The criteria for positive separation will be discussed in Section 6.2.1.4 below.

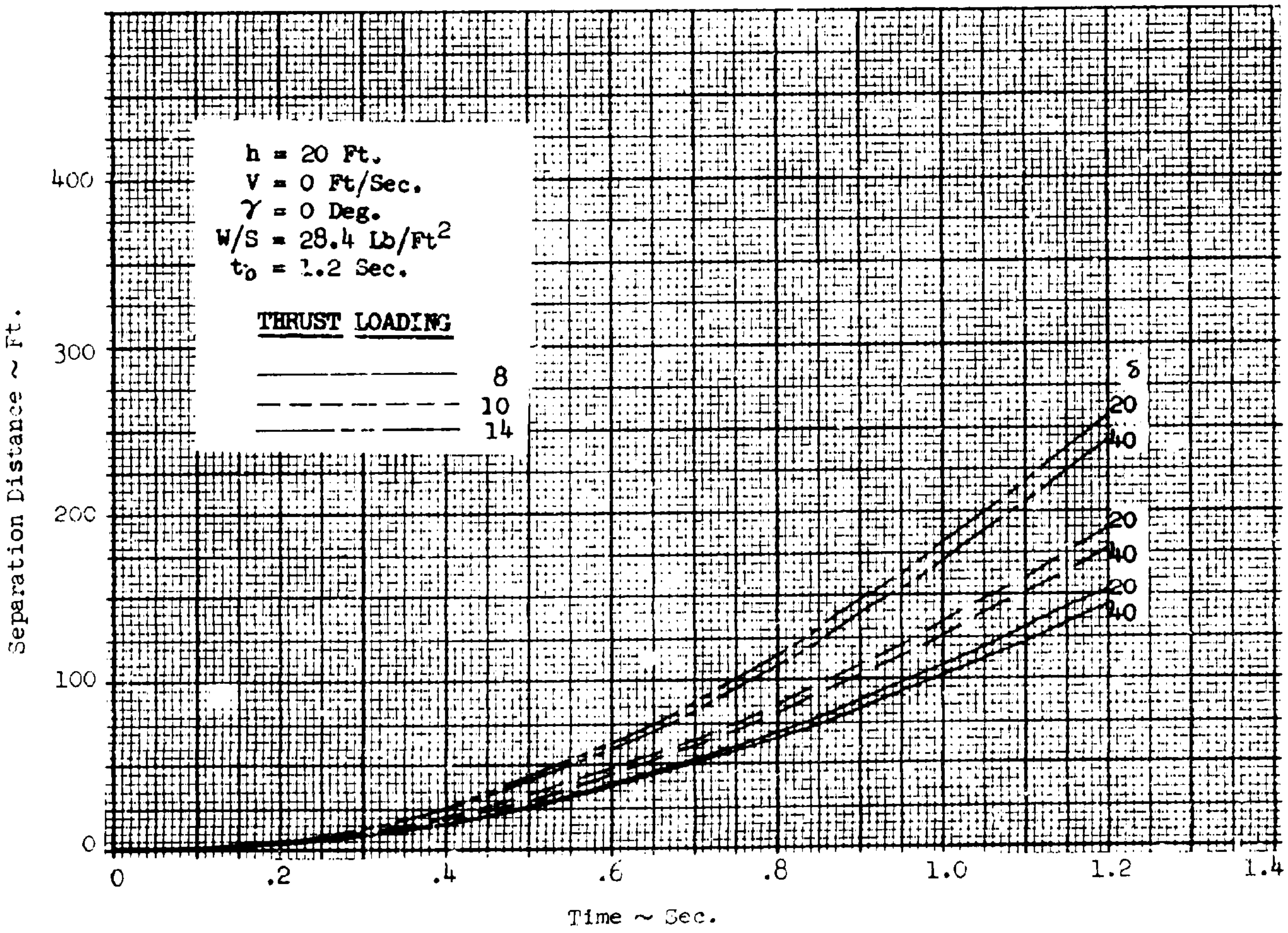


FIGURE 42 - On The Pad Separation Distance - Lifting Body - Horizontal Take-Off
Effect of Thrust, Magnitude and Direction

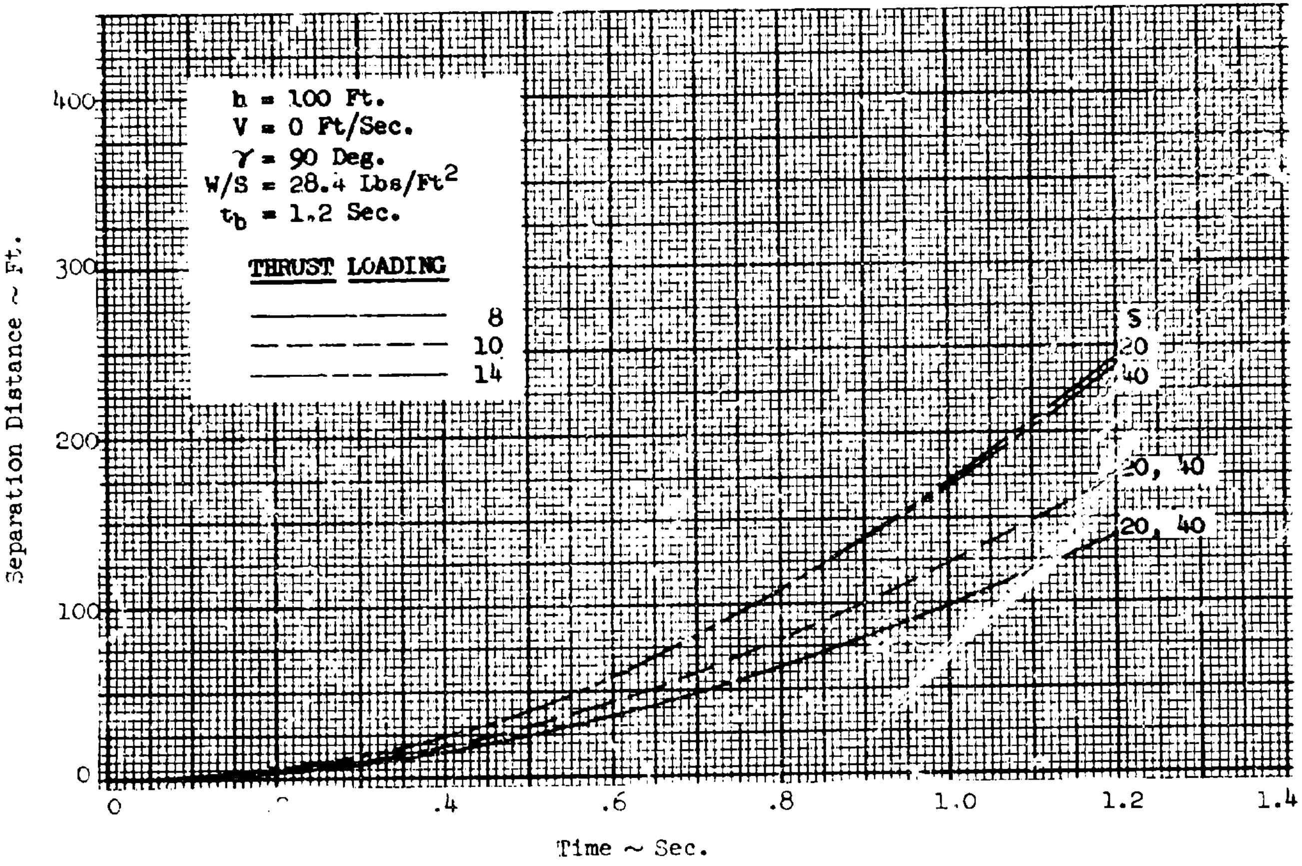


FIGURE 43 - On The Pad Separation Distance - Lifting Body - Vertical Take-Off Effect of Thrust, Magnitude and Direction

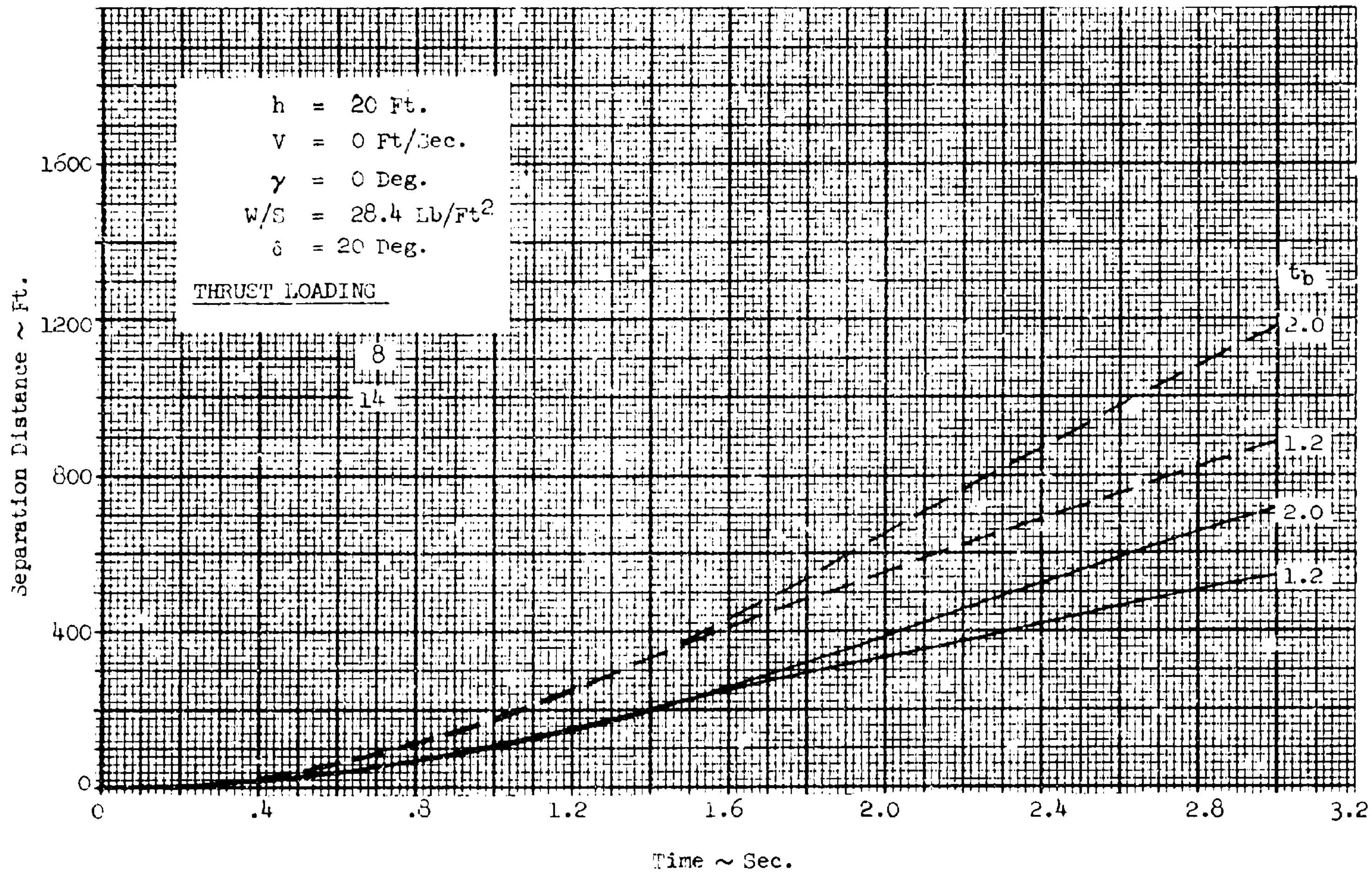


FIGURE 44 - On The Pad Separation Distance - Lifting Body - Horizontal Take-Off
Effect of Rocket Burning Time

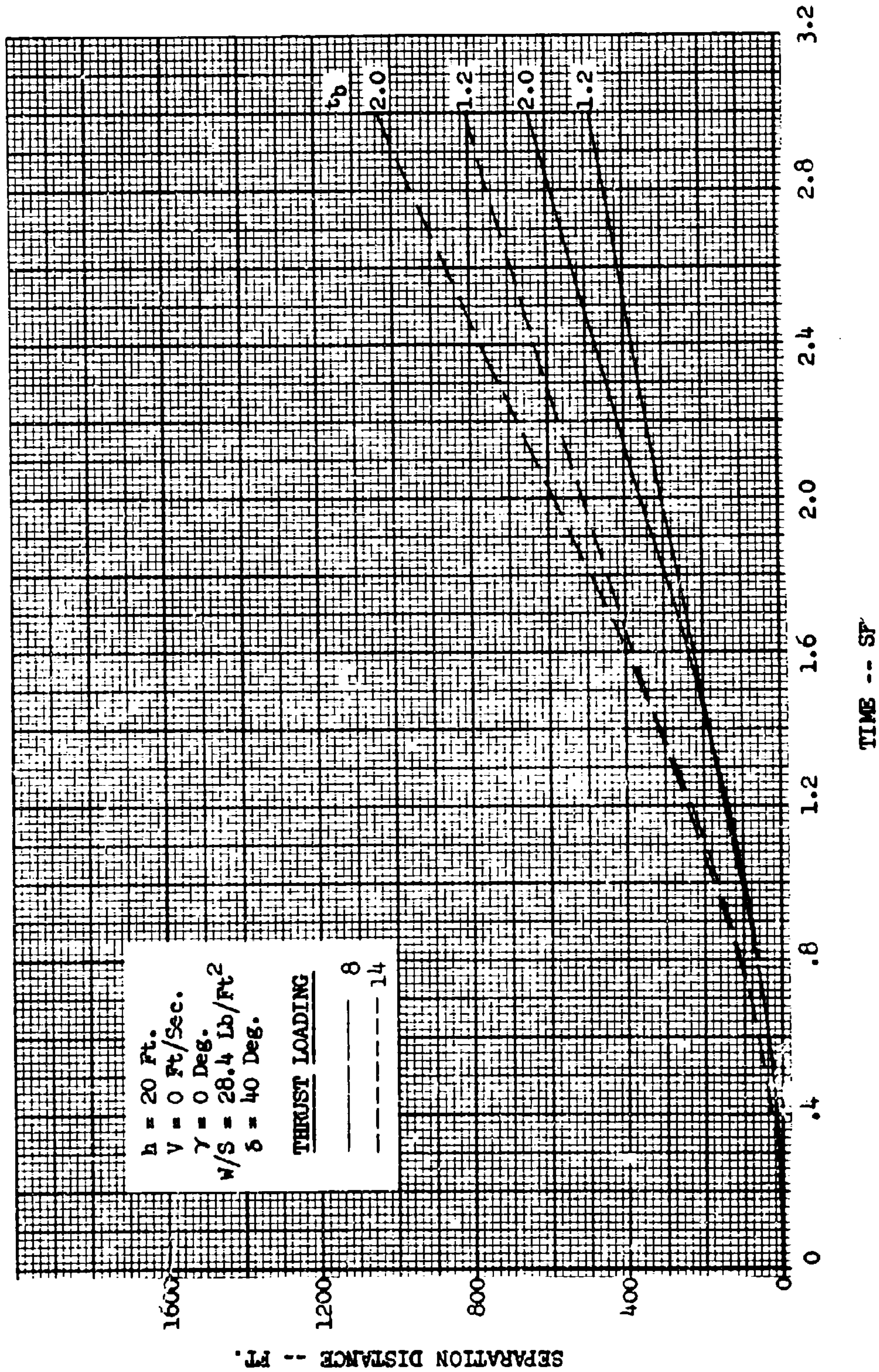


Fig. 45 On The Pad Separation Distance - Lifting Body - Horizontal Take-off
Effect of Rocket Burning Time

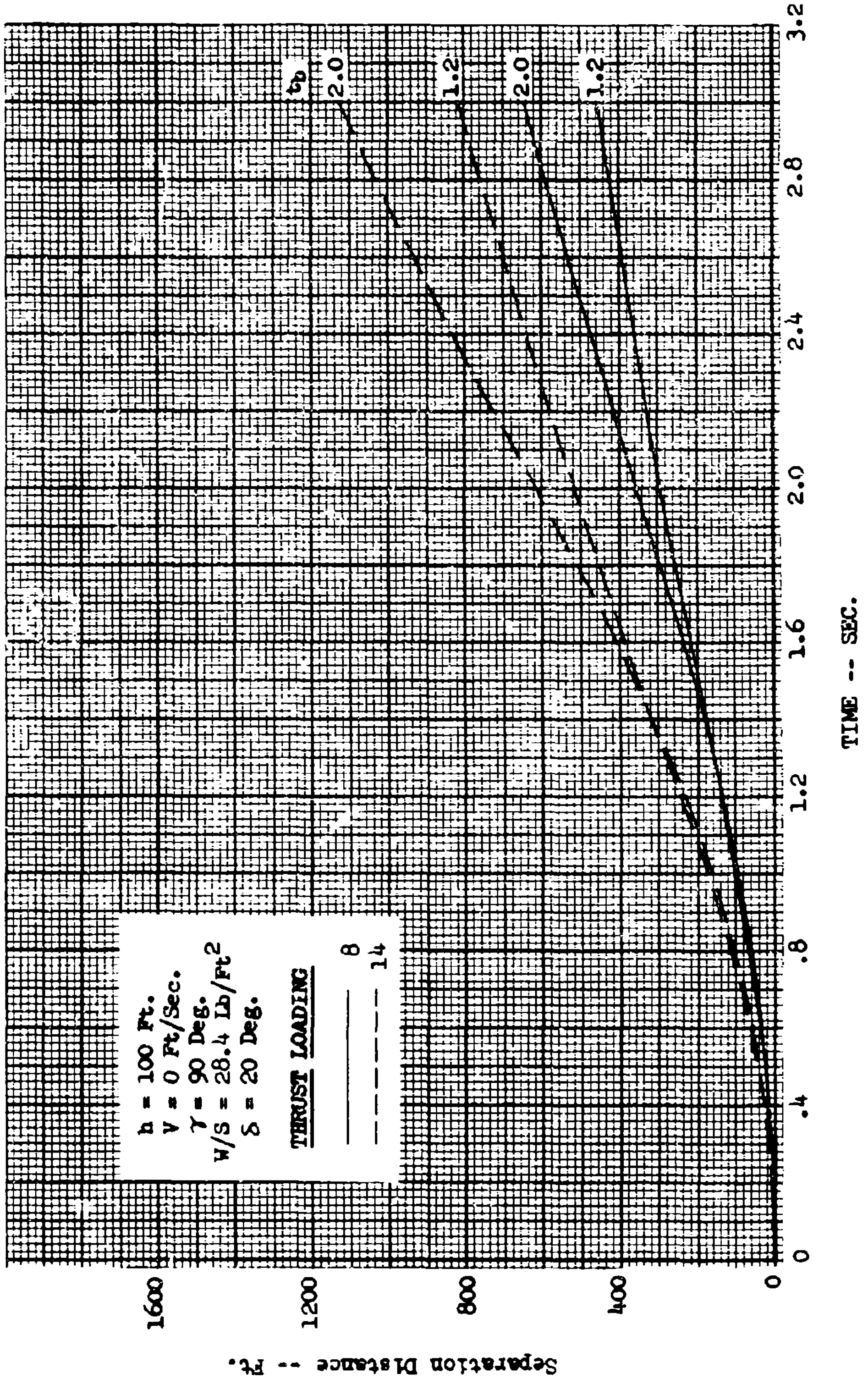


Fig. 46 On The Pad Separation Distance -- Lifting Body -- Vertical Take-off
Effect of Rocket Burning Time

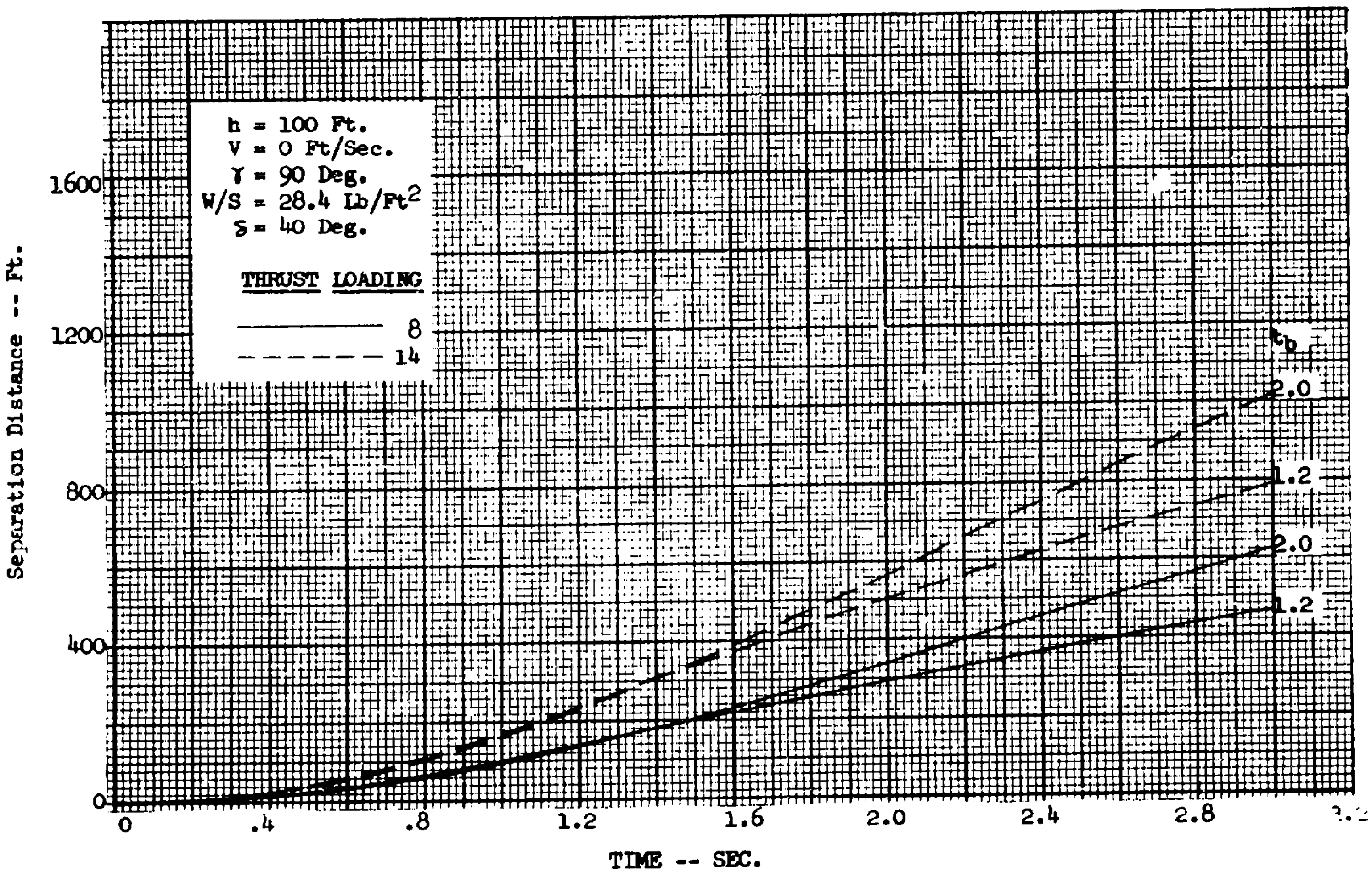


Fig. 47 On The Pad Separation Distance - Lifting Body - Vertical Take-off Effect of Rocket Durning Time

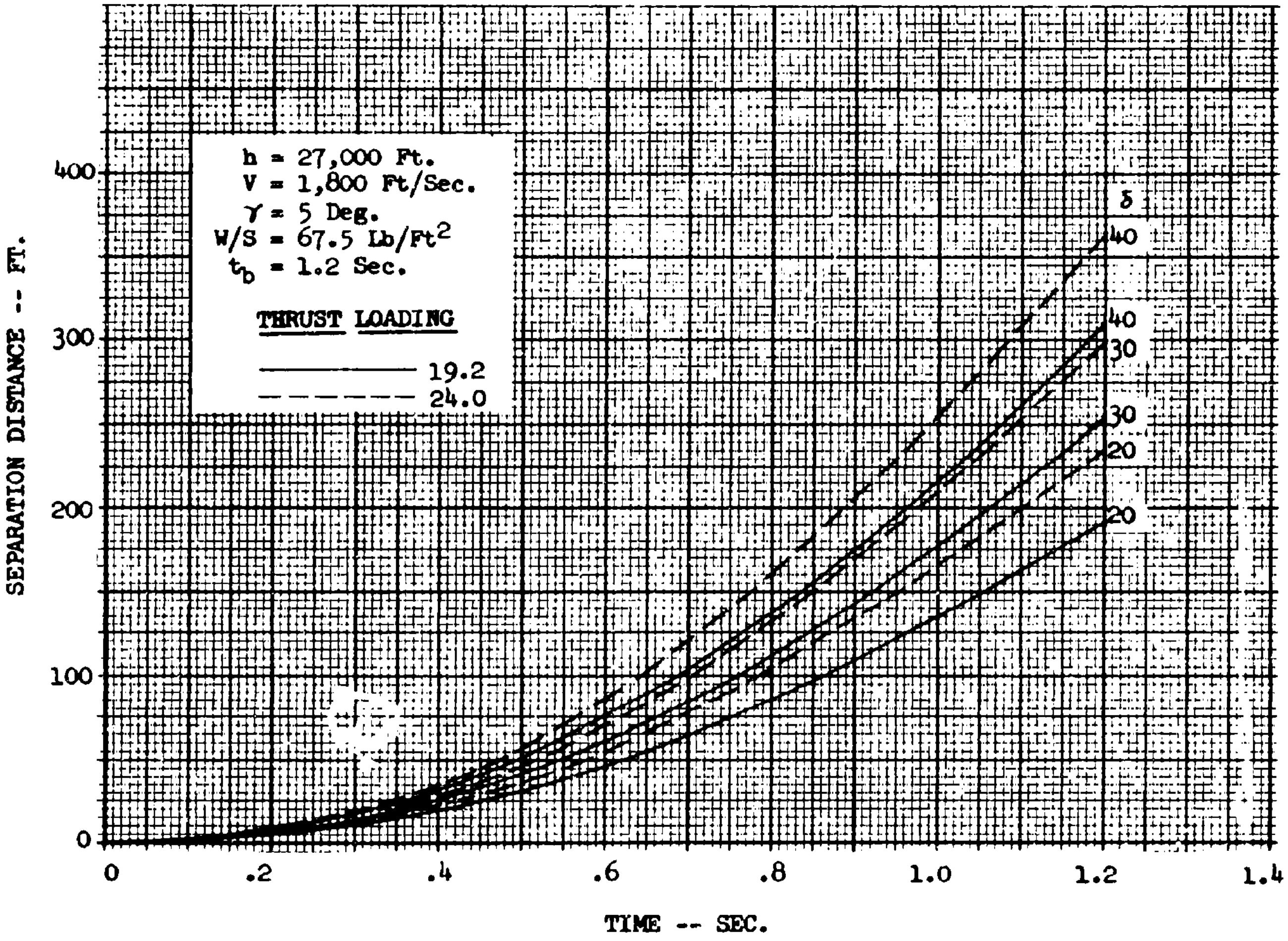


Fig. 48 High Dynamic Pressure Separation Distance - Ballistic Body - Effect of Thrust, Magnitude, and Direction

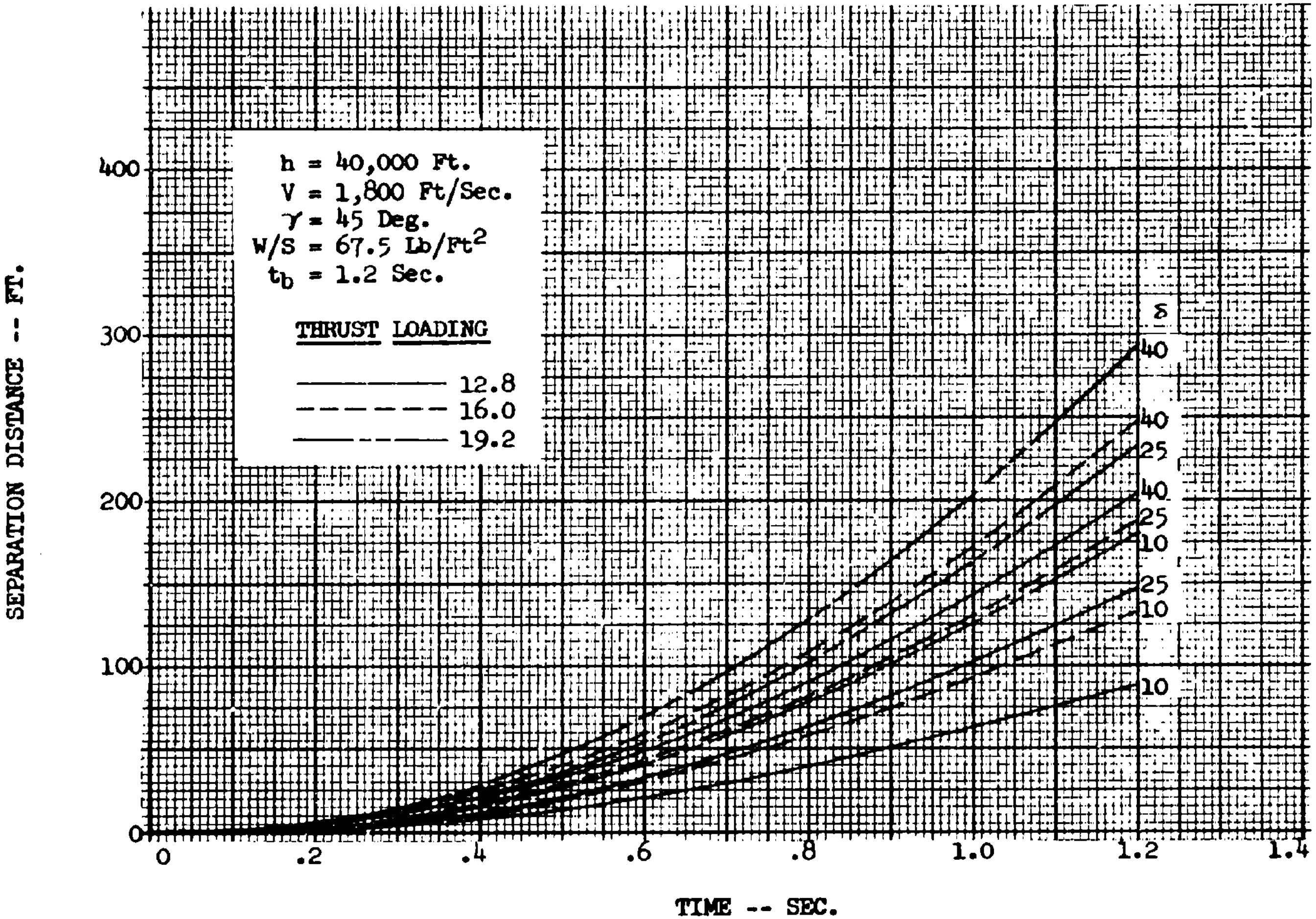


Fig. 49 High Dynamic Pressure Separation Distance - Ballistic Body - Effect of Thrust, Magnitude, and Direction

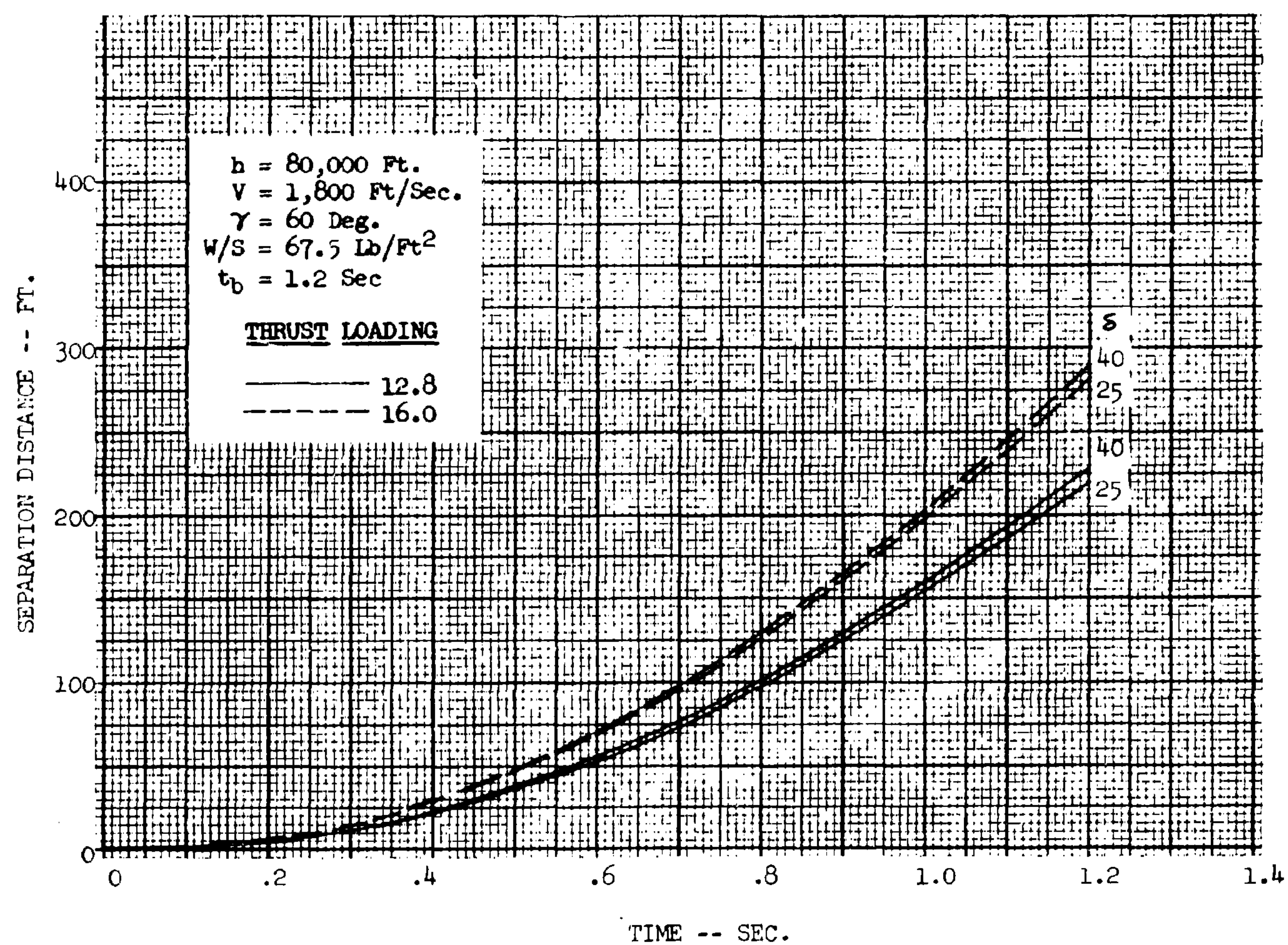


Fig. 50 High Dynamic Pressure Separation Distance - Ballistic Body - Effect of Thrust, Magnitude, and Direction

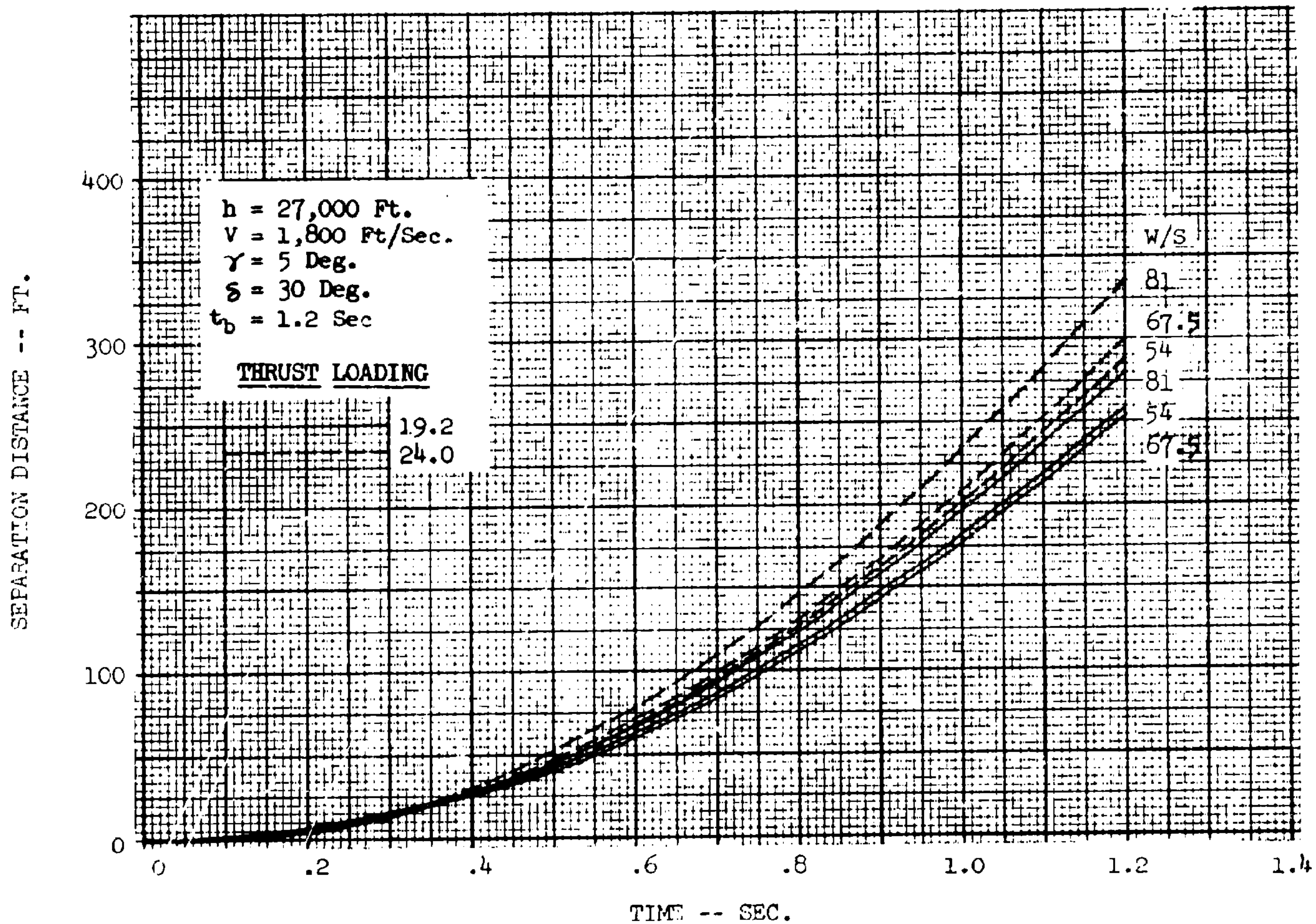


Fig. 51 High Dynamic Pressure Separation Distance - Ballistic Body - Effect of Thrust, Magnitude, and Wing Loading

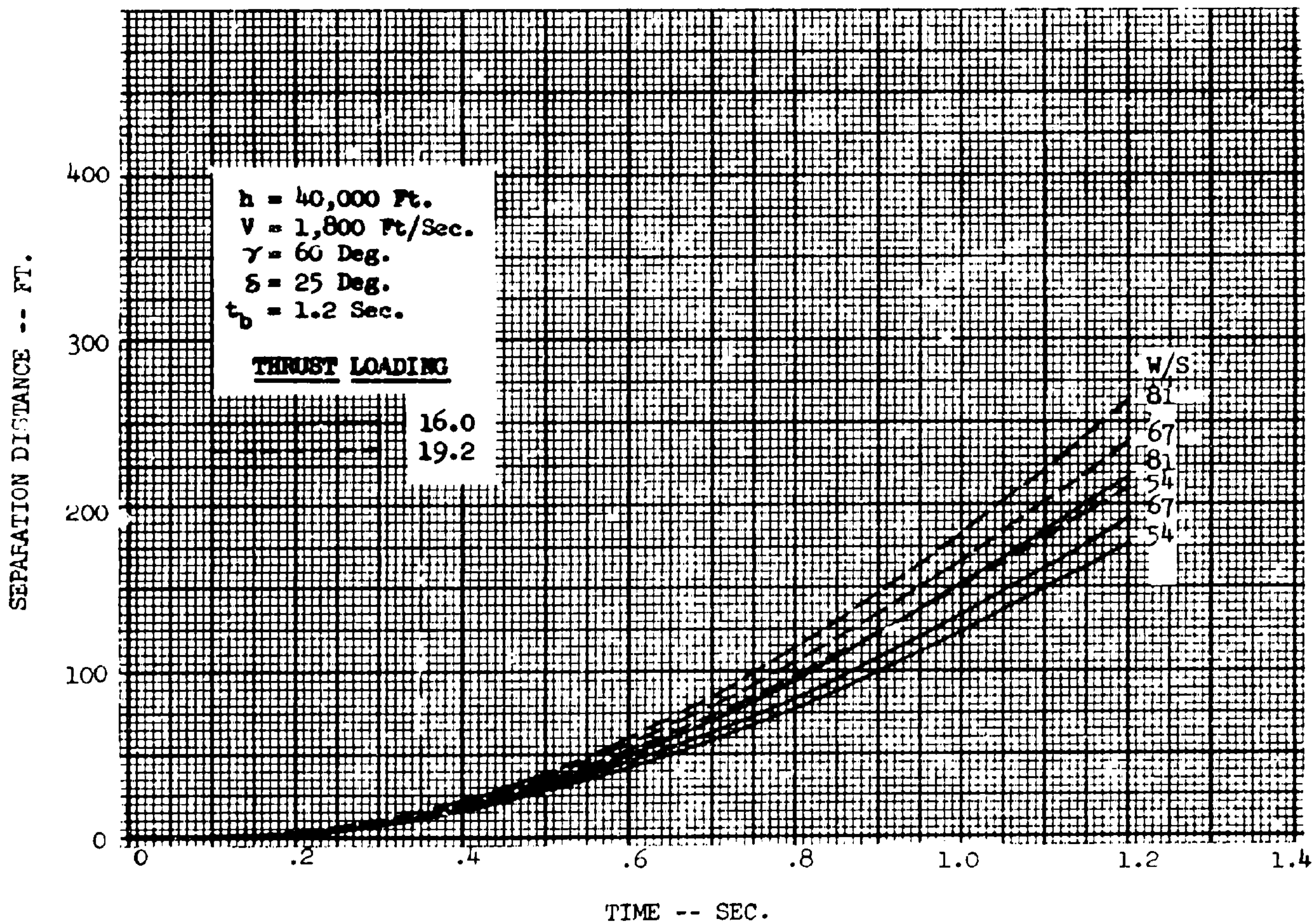


Fig. 52 High Dynamic Pressure Separation Distance - Ballistic Body - Effect of Thrust, Magnitude, and Wing Loading

The results of increasing the separation rocket burning time are presented in Figures 53 and 54 for various thrust loadings. As expected, the longer burning times result in the greater separation distances. Due to an increase in initial weight (increased fuel load) the separation distances are less at the start, but as the rockets burn longer they soon boost the capsule further away from the primary vehicle.

The results of the lifting body at high dynamic pressure are presented in Figures 55 through 59. The lifting body results show the same trends as the ballistic body except for the wing loading variation. The low wing loading resulted in the best separation performance for the lifting body while the high wing loading was best for the ballistic body. This can be attributed to the greater effect of lift with a lower wing loading.

High Mach Number. High Mach number escape is not critical from the standpoint of thrust requirements or separation characteristics. It is critical however from the standpoint of clearance between two escape capsules. In order to present a more complete set of separation distance characteristics, hypersonic separation data has been adapted from the studies of Reference 8 and is presented herein. Figure 60 presents the separation distance characteristics as a function of time for the ballistic body capsule, indicating the effect of thrust loading. The separation distance characteristics of the lifting body as a function of time are presented in Figure 61 showing the effects of thrust loading and thrust angle.

6.2.1.4 Separation Criteria. There are two basic criteria applicable to the separation of a capsule from a vehicle. These are that the accelerations remain within the human tolerance limits and that the capsule have a positive separation force at maximum thrust.

Acceleration. The ability of a human body to withstand accelerations in various directions has been fairly well explored. Figure 8 is a generalized curve that shows these tolerable accelerations versus time. These data have been used as guidelines for human tolerance to accelerations during this escape investigation.

Accelerations during an escape maneuver arise from two sources; escape rocket thrust and aerodynamic loads. The escape rocket thrust is critical at zero-zero escape when there are no relieving aerodynamic forces. At these conditions, the thrust/weight must be less than the acceleration limits given in Figure 8.

The aerodynamic loads are critical at maximum dynamic pressure. The critical condition is generally after rocket burnout since during thrusting the high aerodynamic forces in the drag direction are opposed by the escape rocket thrust thus reducing the load factor. At burnout the resultant aerodynamic load factor is given by

$$R = \frac{q \, C_D S}{W} \sqrt{1 + (L/D)^2}$$

where

q = dynamic pressure - lbs/sq. ft.
C_D = drag coefficient
S = reference area - sq. ft.
W = weight - lbs.
L_D = lift to drag ratio

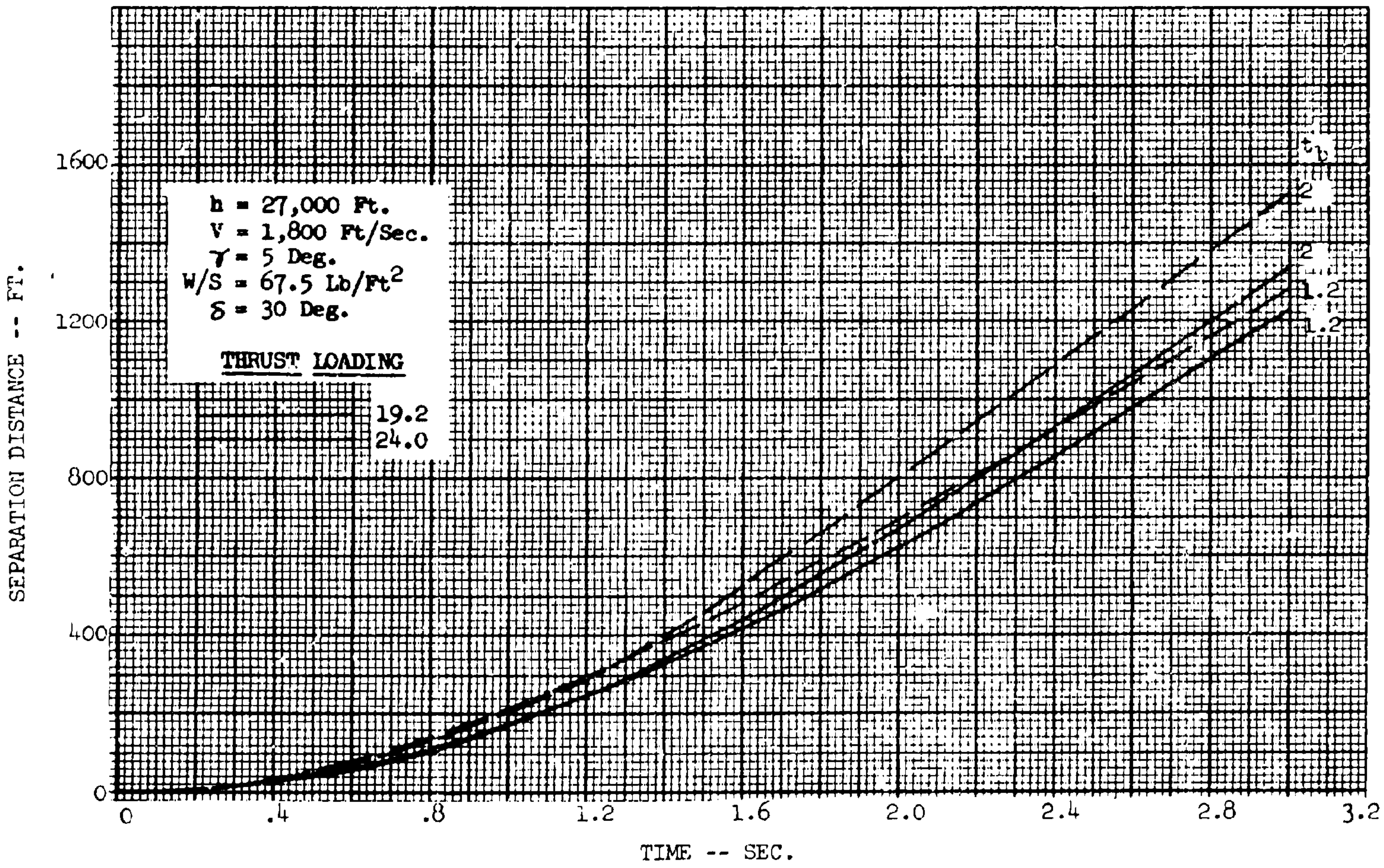


Fig. 53 High Dynamic Pressure Separation Distance - Ballistic Body - Effect of Rocket Burning Time

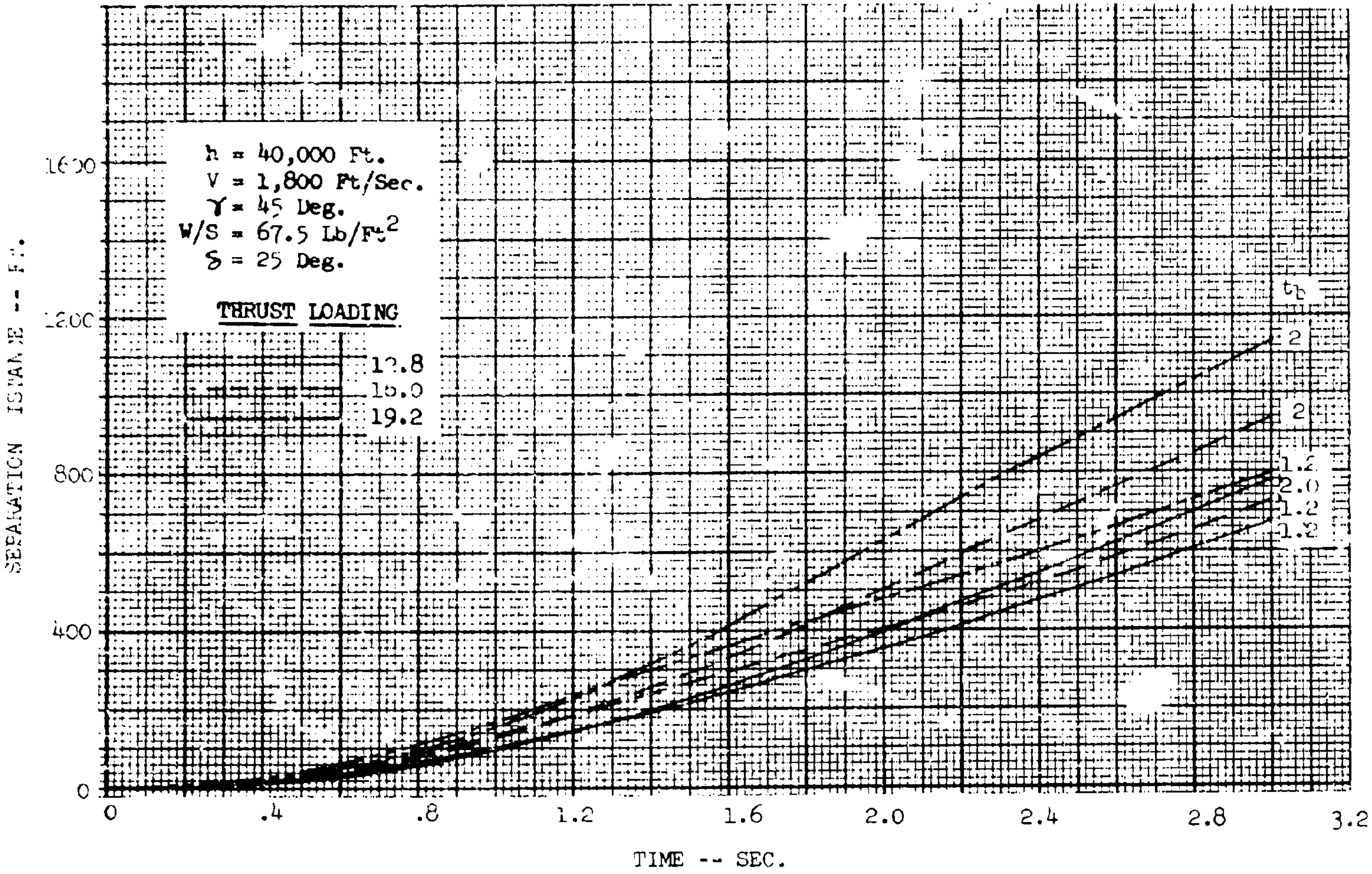


Fig. 54 High Dynamic Pressure Separation Distance - Ballistic Body - Effect of Rocket Burning Time

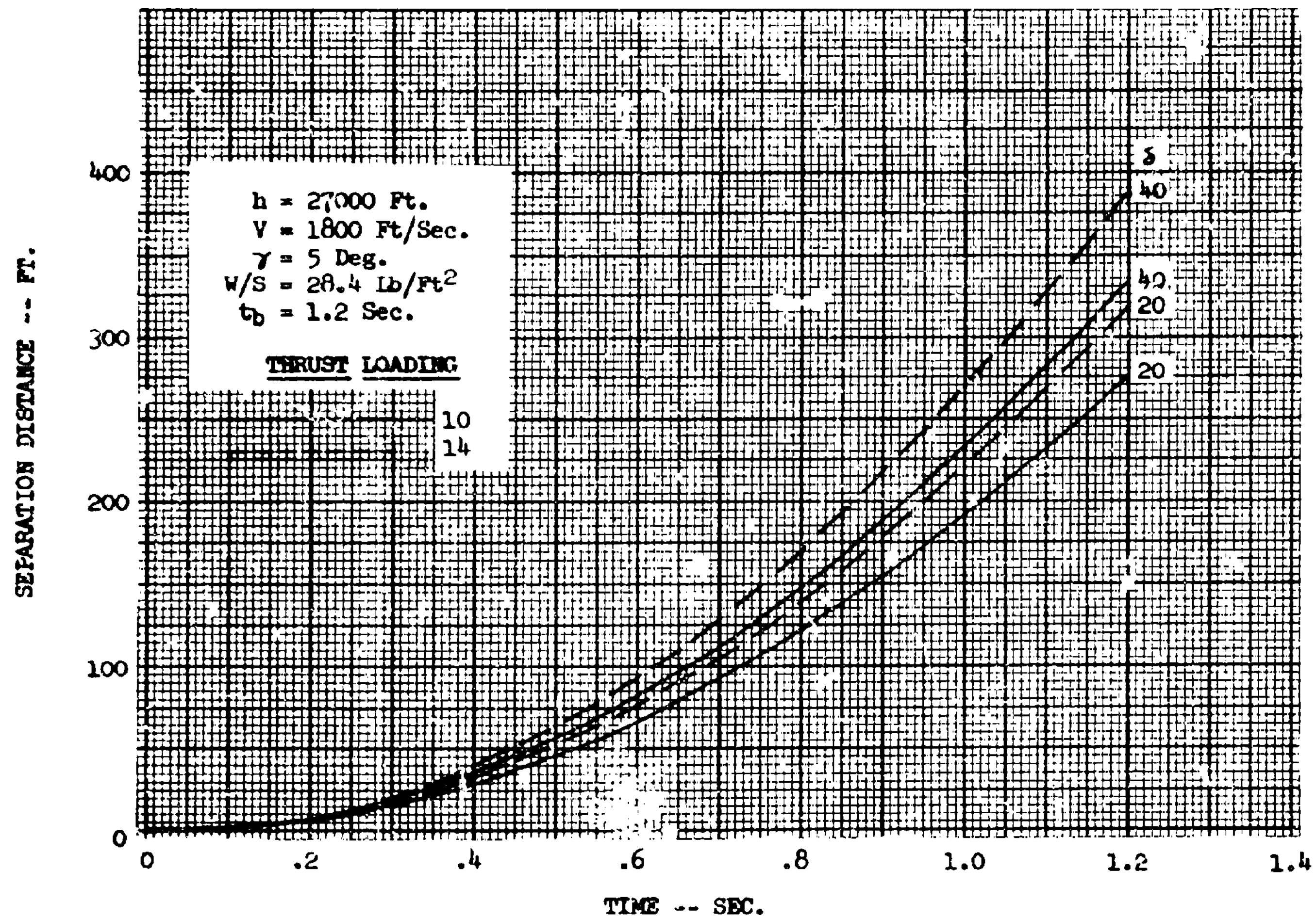


Fig. 55 High Dynamic Pressure Separation Distance - Lifting Body - Effect of Thrust Magnitude and Direction

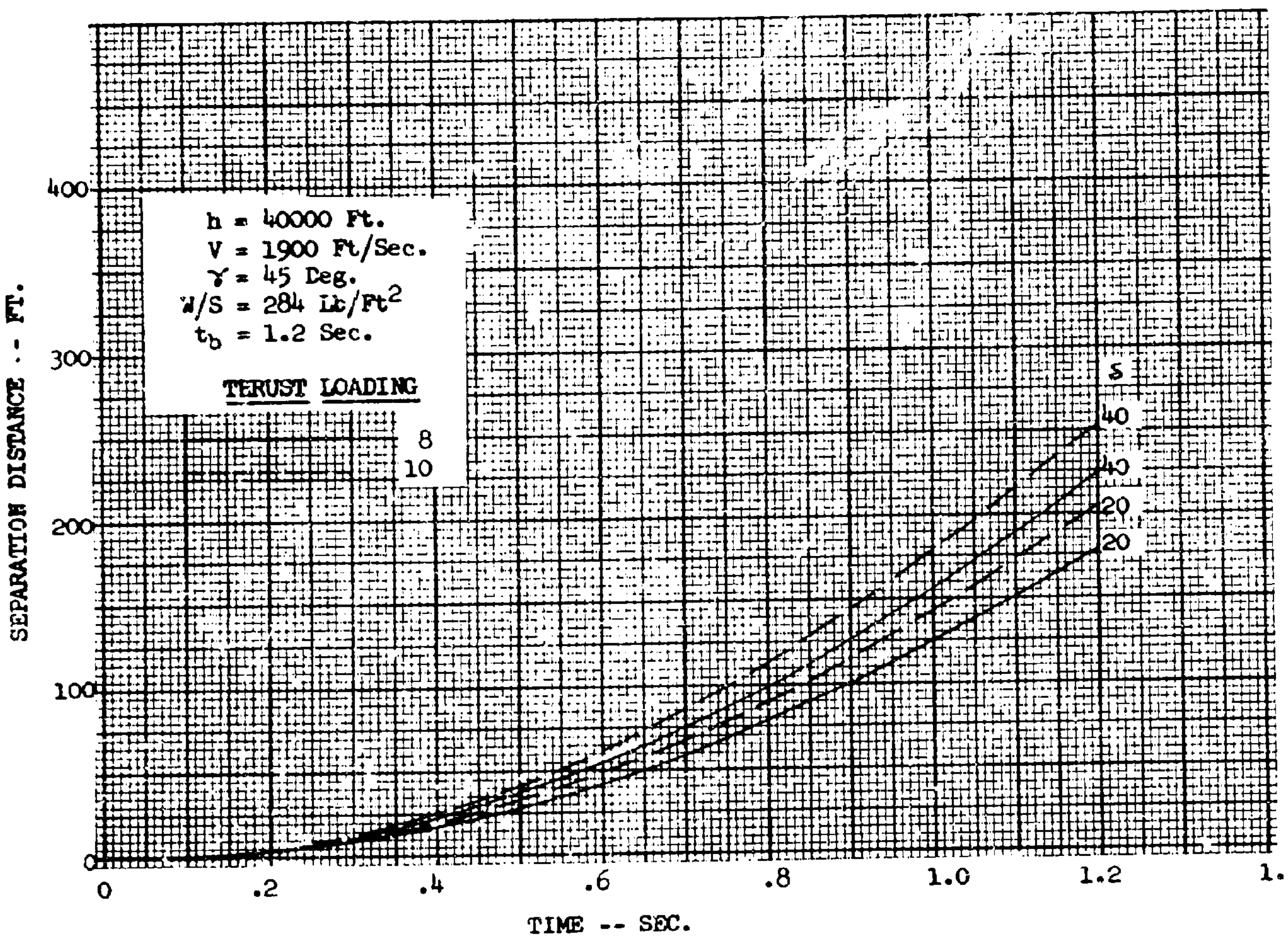


Fig. 56 High Dynamic Pressure Separation Distance - Lifting Body - Effect of Thrust Magnitude and Direction

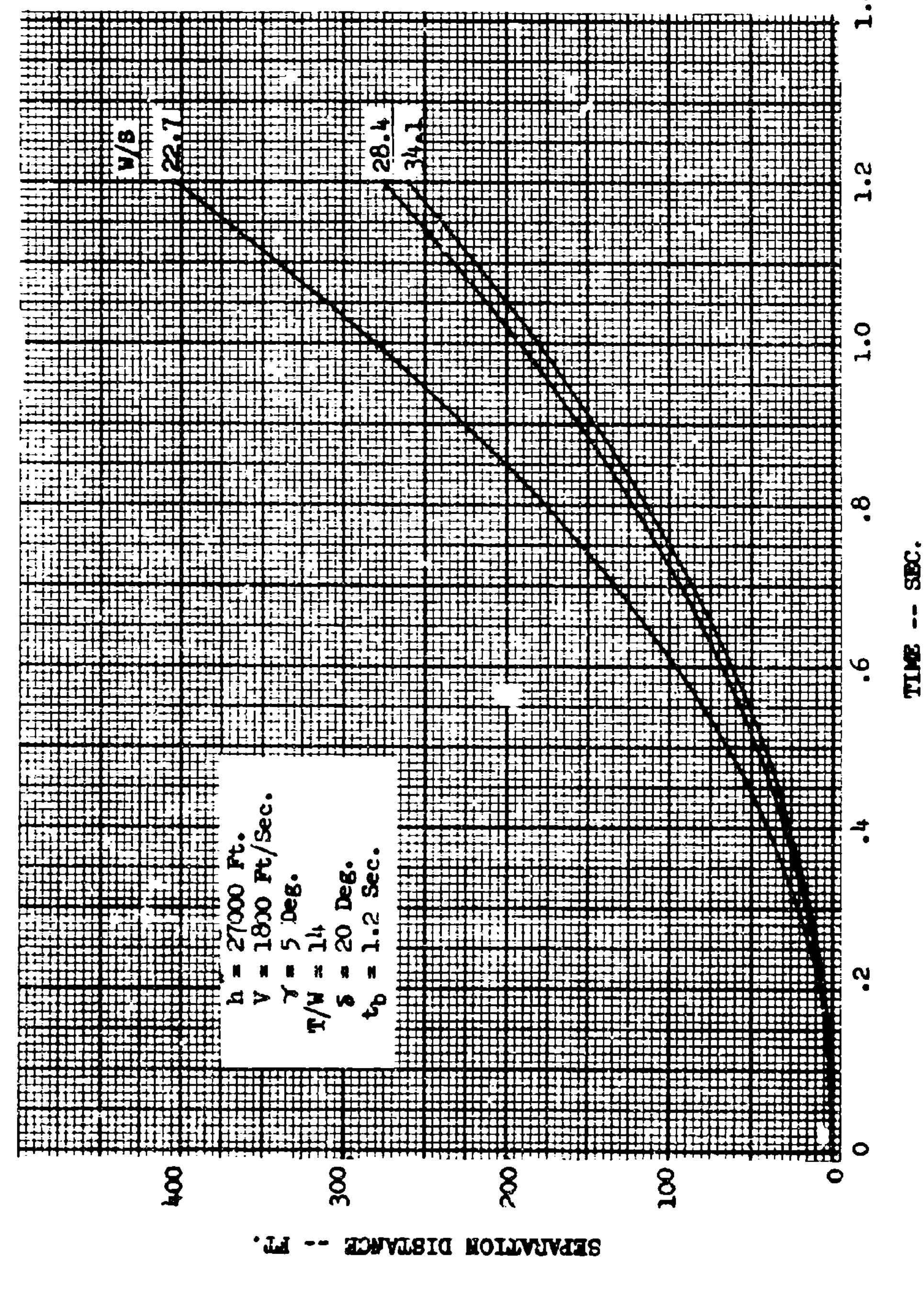


Fig. 57 High Dynamic Pressure Separation Distance - Lifting Body - Effect of Wing Loading

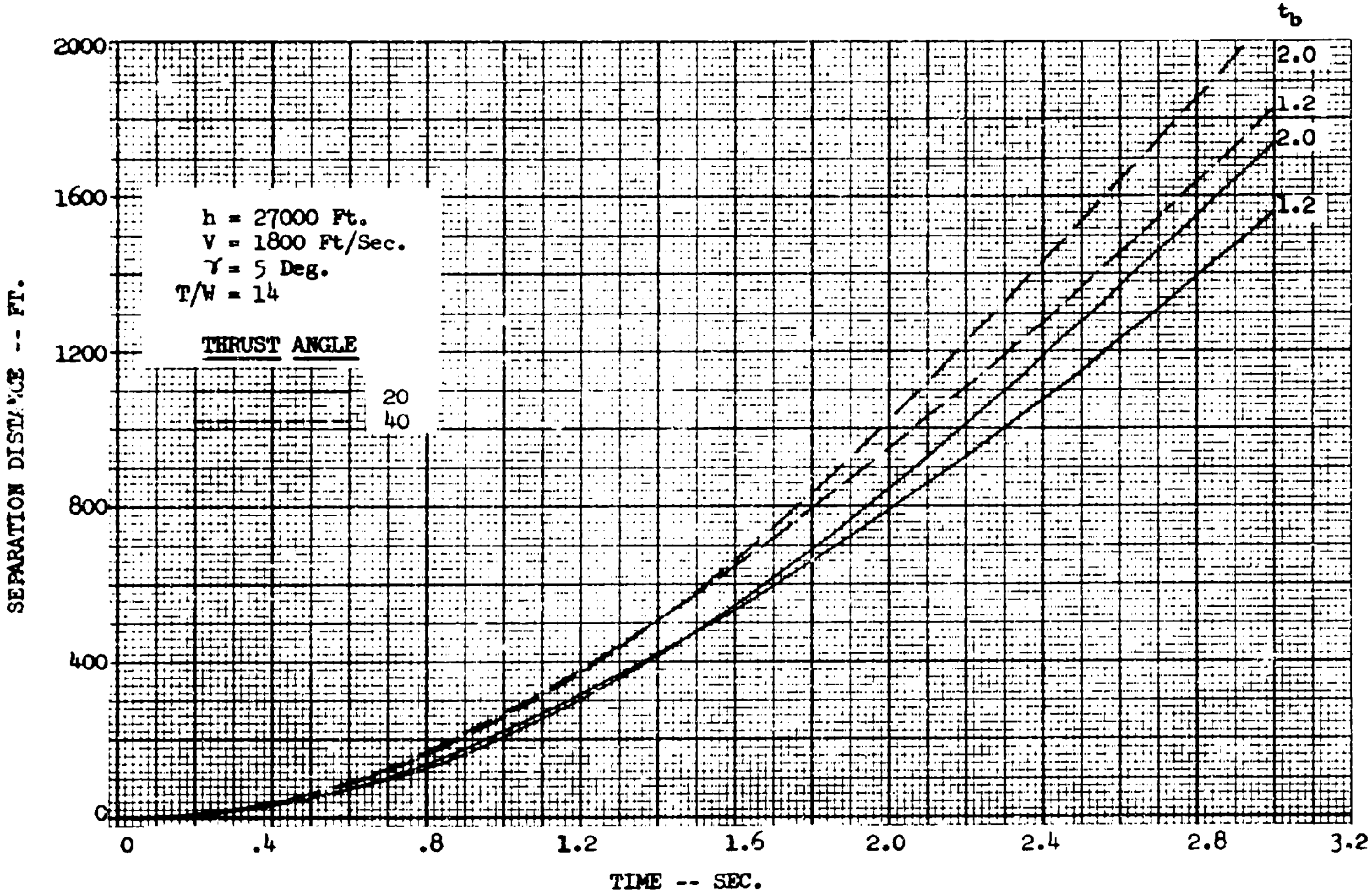


Fig. 58 High Dynamic Pressure Separation Distance - Lifting Body - Effect of Rocket Burning Time

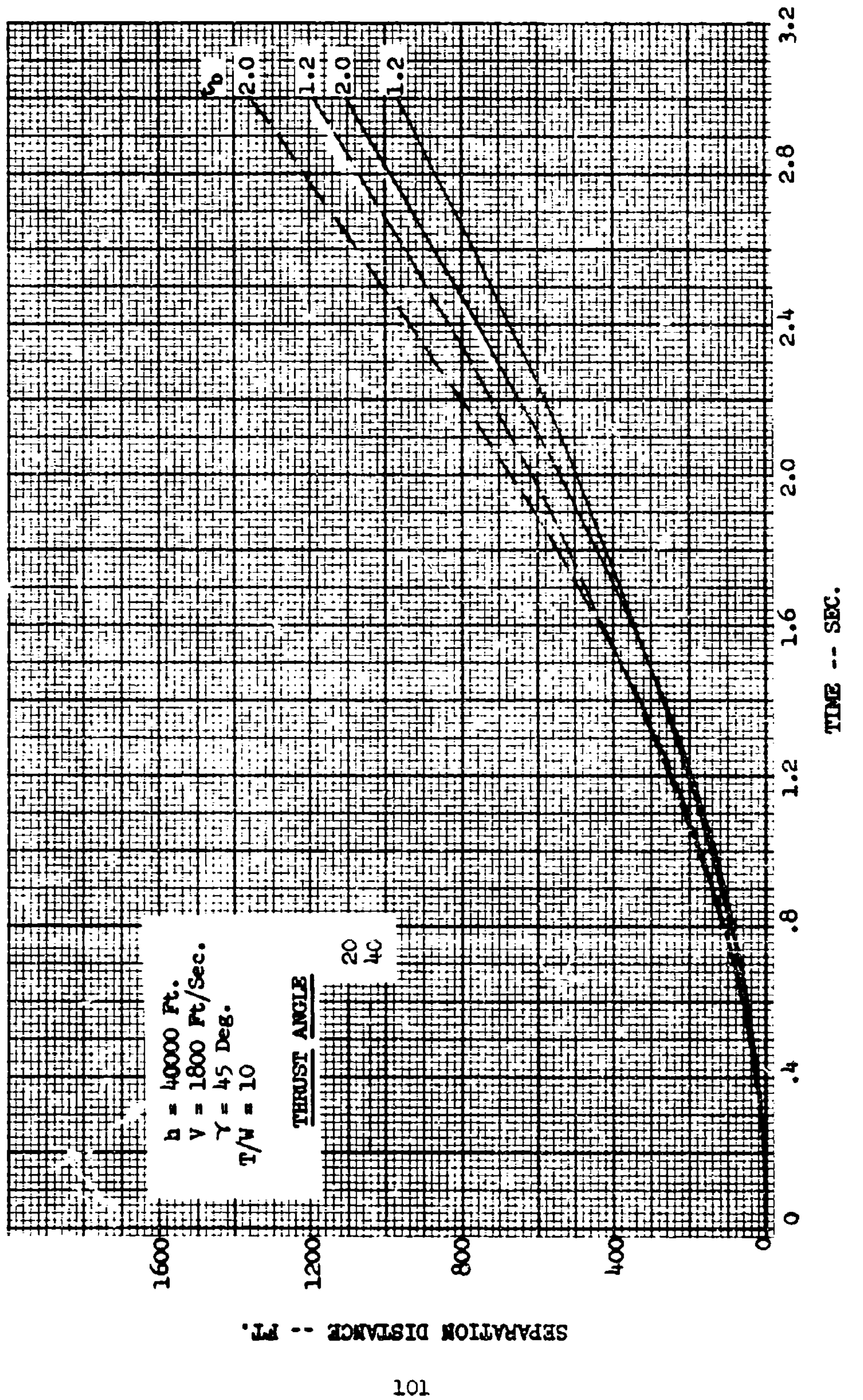


FIG. 59 High Dynamic Pressure Separation Distance - Lifting Body - Effect of Rocket Burning Time

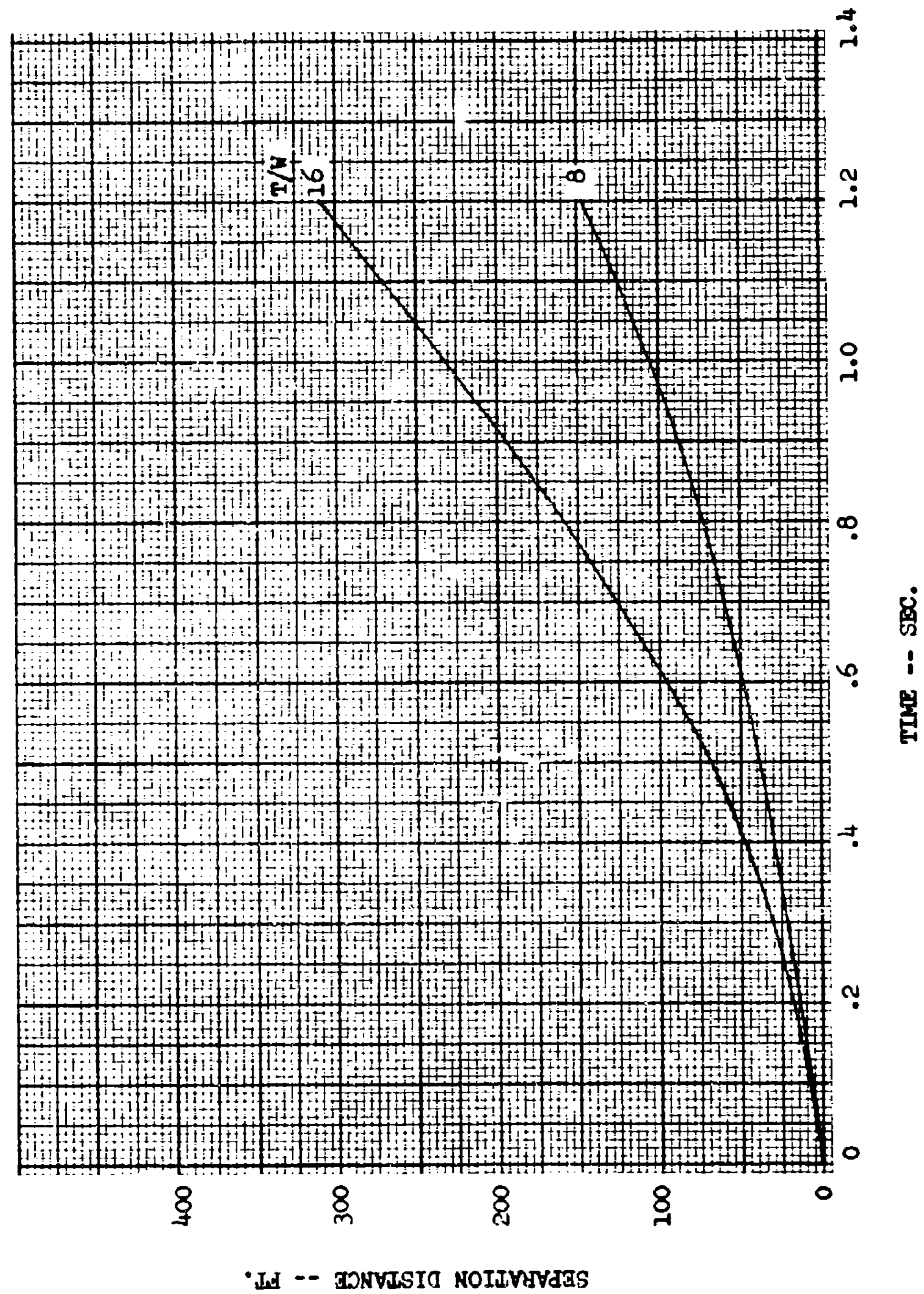


Fig. 60 Hypersonic Separation Distance - Ballistic Body - Effect of Thrust Magnitude

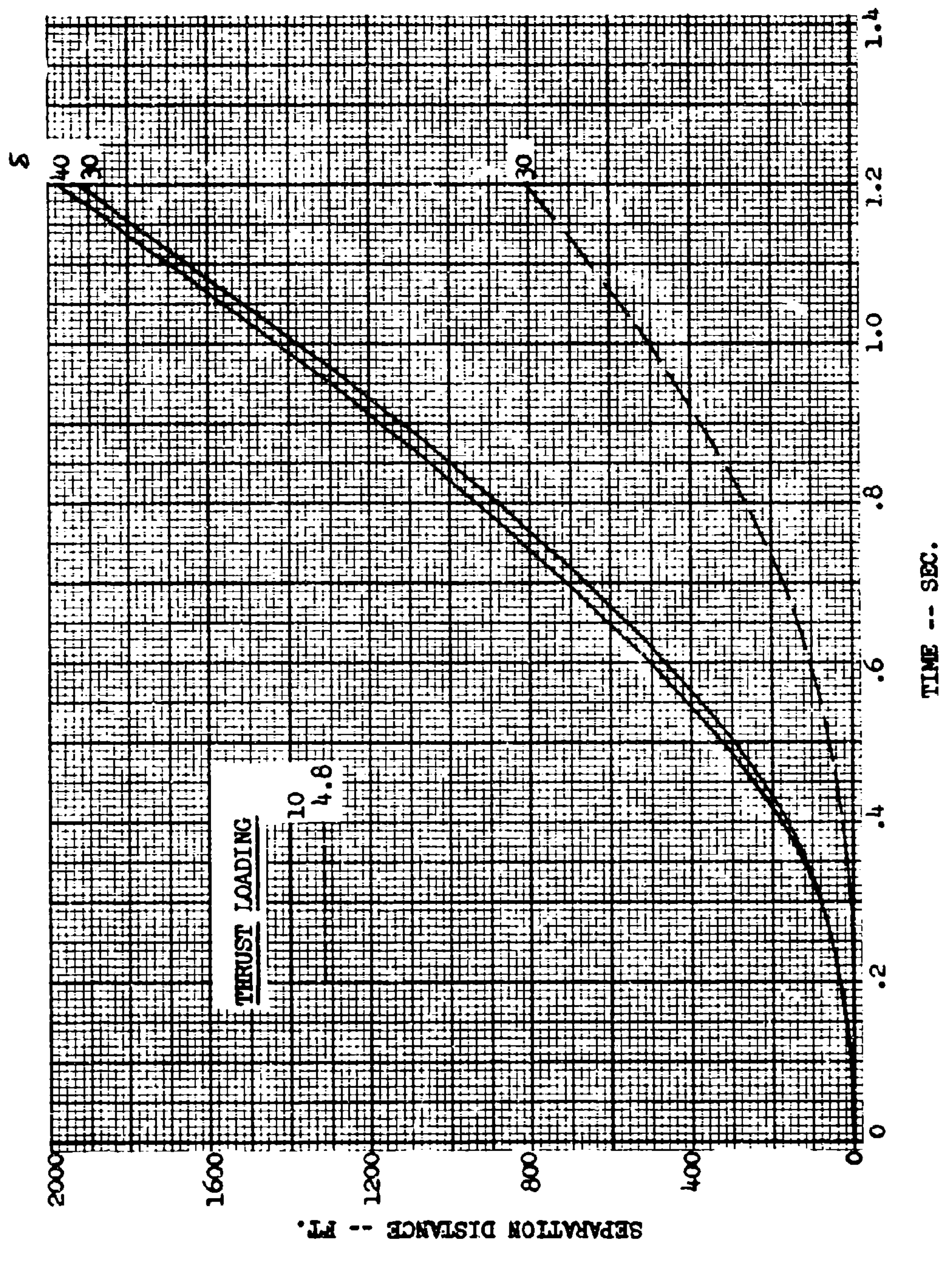


Fig. 61 Hypersonic Separation Distance - Lifting Body - Effect of Thrust Magnitude and Direction

Figures 62 through 64 present resultant aerodynamic load factor as a function of dynamic pressure, lift-to-drag ratio and drag parameter C_DS/W. The maximum allowable load factor from Figure 8 is superimposed on these figures. This data is presented to be used only as a guide in selecting escape capsule aerodynamic characteristics.

Separation Force. In order to obtain positive separation of a capsule from a vehicle it is necessary to have a positive force. The maximum separation force is required at maximum dynamic pressure when the air loads resisting separation are at their maximum.

It was assumed for this study that positive separation occurred along the body longitudinal axis. Separation in other directions would change the quantitative values presented but not the qualitative effects of the various parameters considered. The force equation along the body axis is presented below for an acceleration of zero:

$$T' = T/W \cos \delta = \frac{C_DS}{W} q \left[\cos \alpha - L/D \sin \alpha\right] + \sin (\alpha + \gamma)$$

where

T	=	Thrust
δ	=	Thrust inclination to centerline
C_D	=	Drag Coefficient
S	=	Reference Area
W	=	Weight
q	=	Dynamic pressure
α	=	Angle of Attack
L/D	=	Lift-to-drag ratio
γ	=	Flight path angle

The effect of dynamic pressure, lift-to-drag, angle of attack, flight path angle and the drag parameter C_DS/W on the separating force was determined. The results are presented in Figures 65 through 68 in terms of a thrust parameter (thrust-to-weight ratio times the cosine of the thrust angle).

6.2.1.5 Summary. This data on capsule-vehicle separation which has been discussed above has been presented in this report on crew escape for two stage manned aerospace vehicles to serve as guidelines in selecting the geometric, aerodynamic and propulsion characteristics for escape capsules for use in two stage vehicles. The data has been presented as generalized data and should be used as such.

6.2.2 CAPSULE - CAPSULE SEPARATION. The most significant problem in regard to escape separation characteristics for a two stage aerospace vehicle with two separated crew compartments is the problem of collision between the two capsules. This problem was investigated considering the effect of variations on the following parameters:

1. Separation rocket thrust and direction

2. Rocket burning time

3. Initial separation distance

4. Time delay between initiation of escape

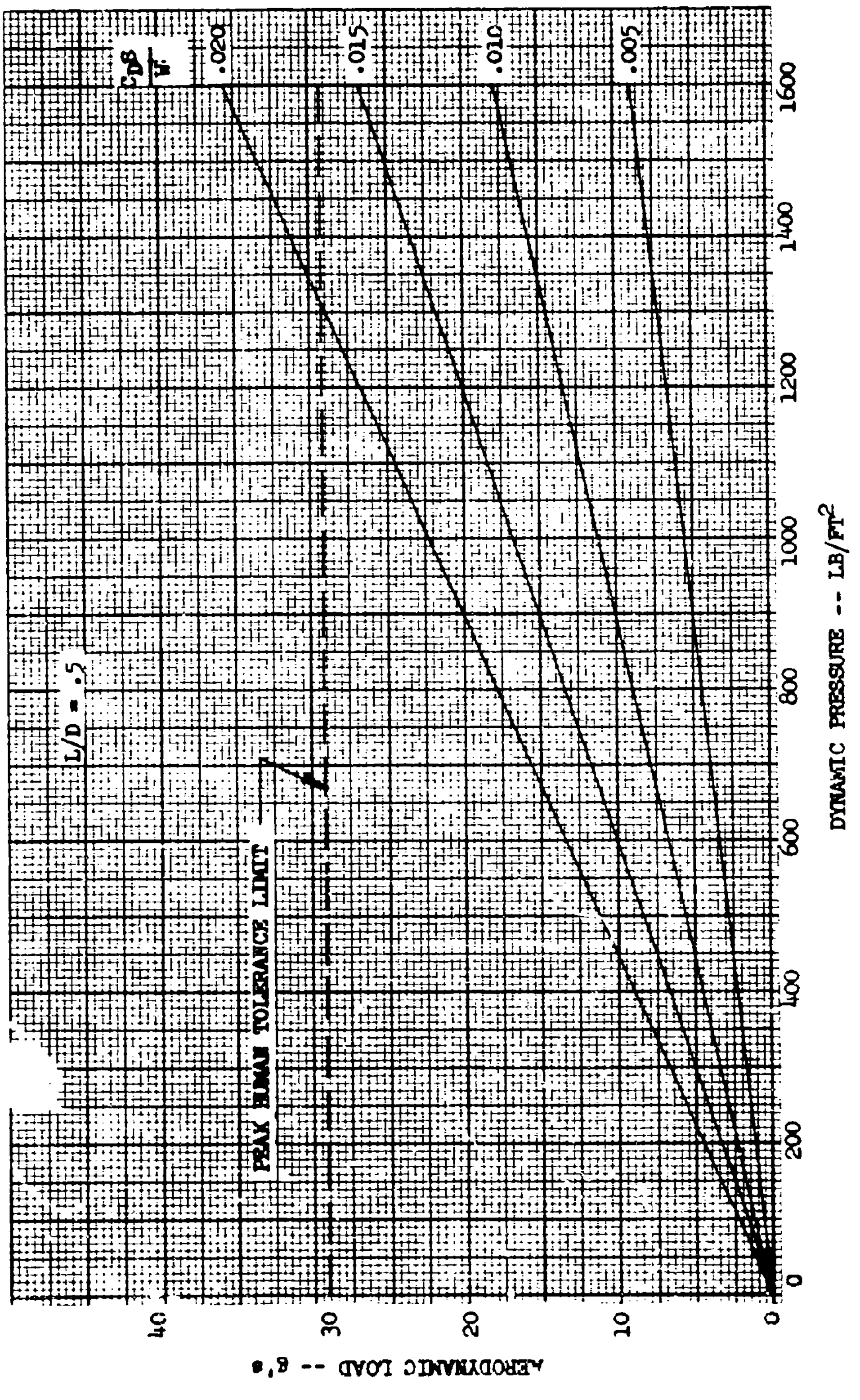


Fig 62 Acceleration Criteria - Effect of Dynamic Pressure and Drag Factor

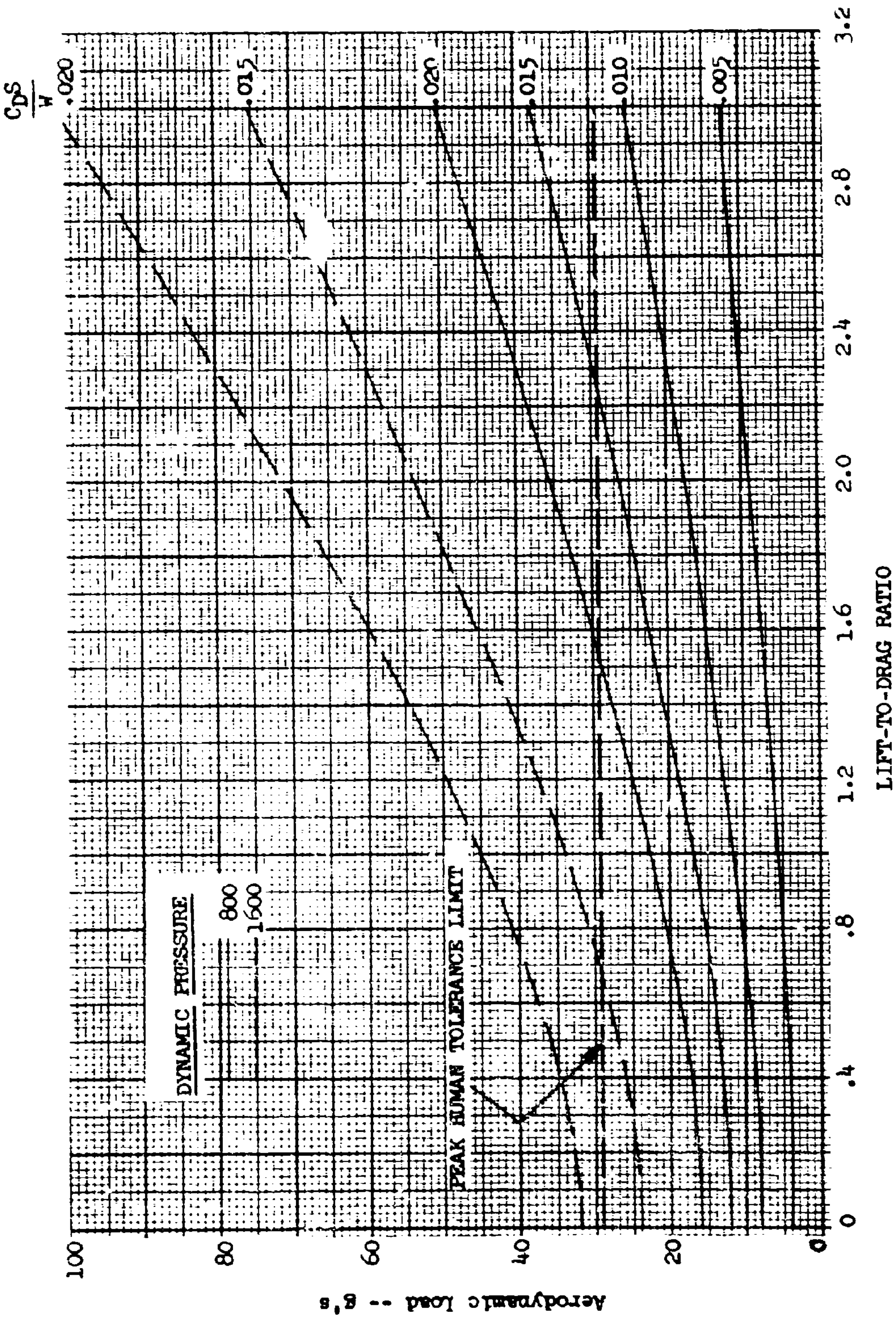


Fig. 63 Acceleration Criteria - Effect of Lift-to-Drag Ratio

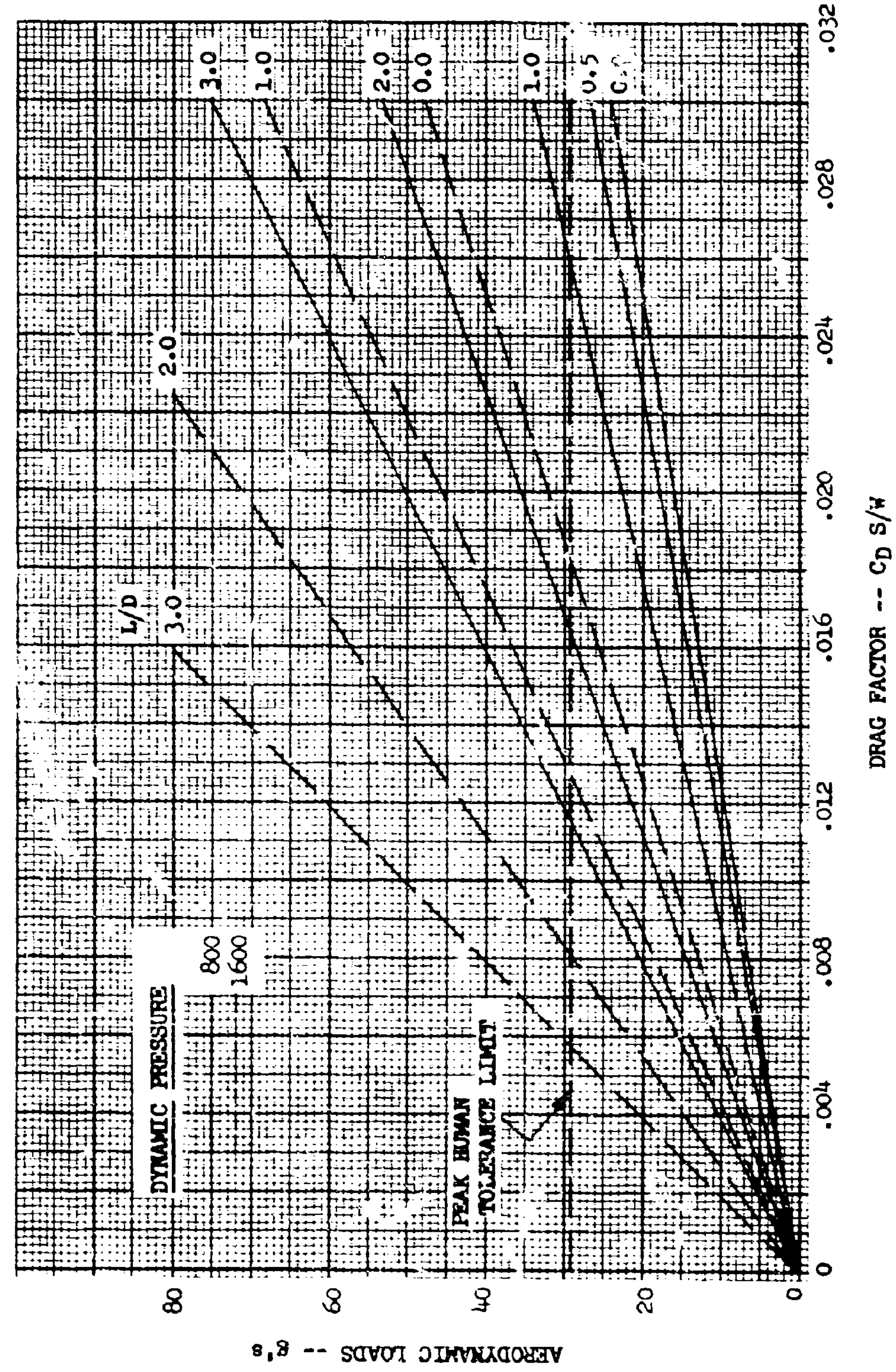


Fig. 64 Acceleration Criteria - Effect of Drag Factor

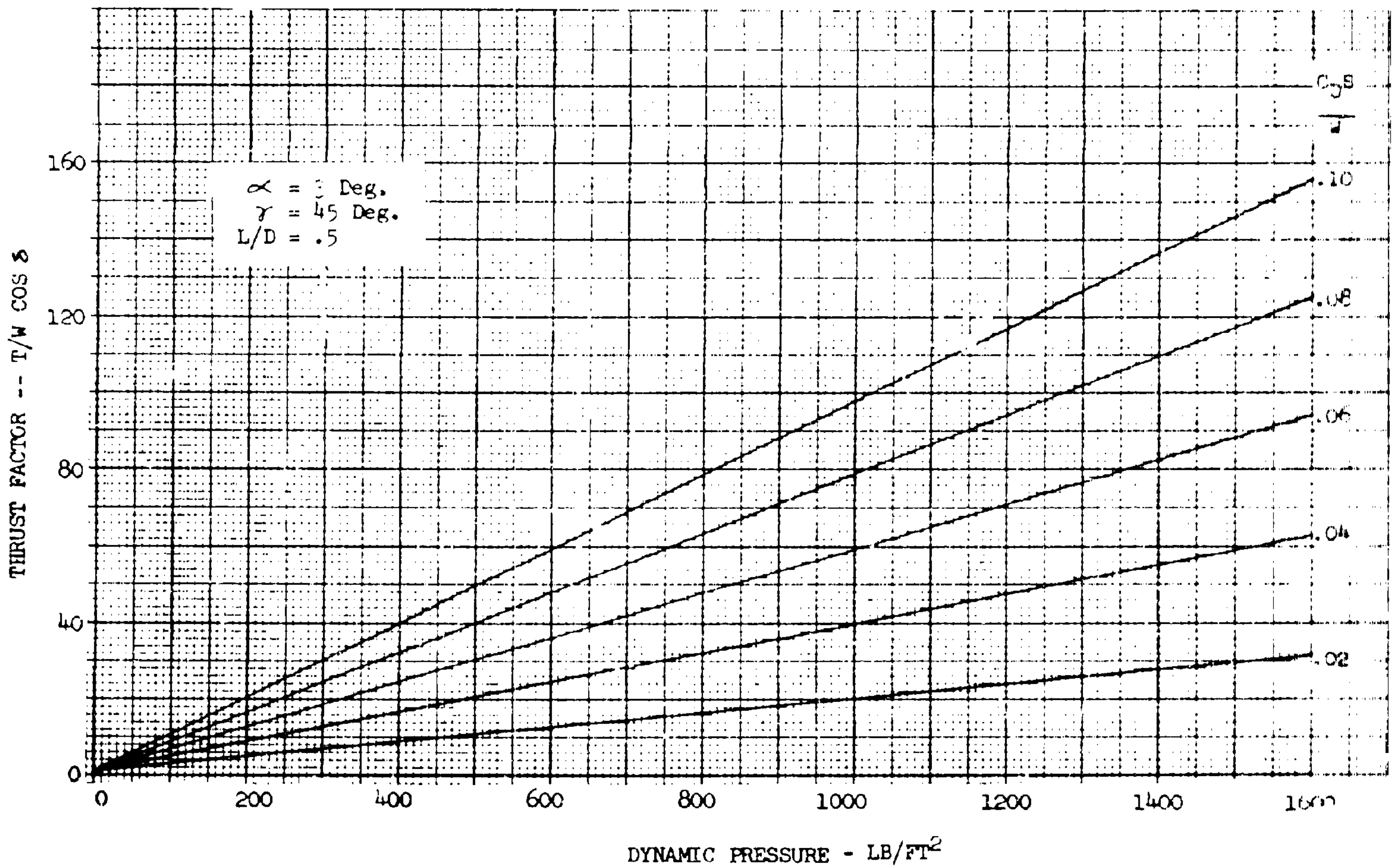


Fig. 65 Separation Criteria - Effect of Dynamic Pressure and Drag Factor

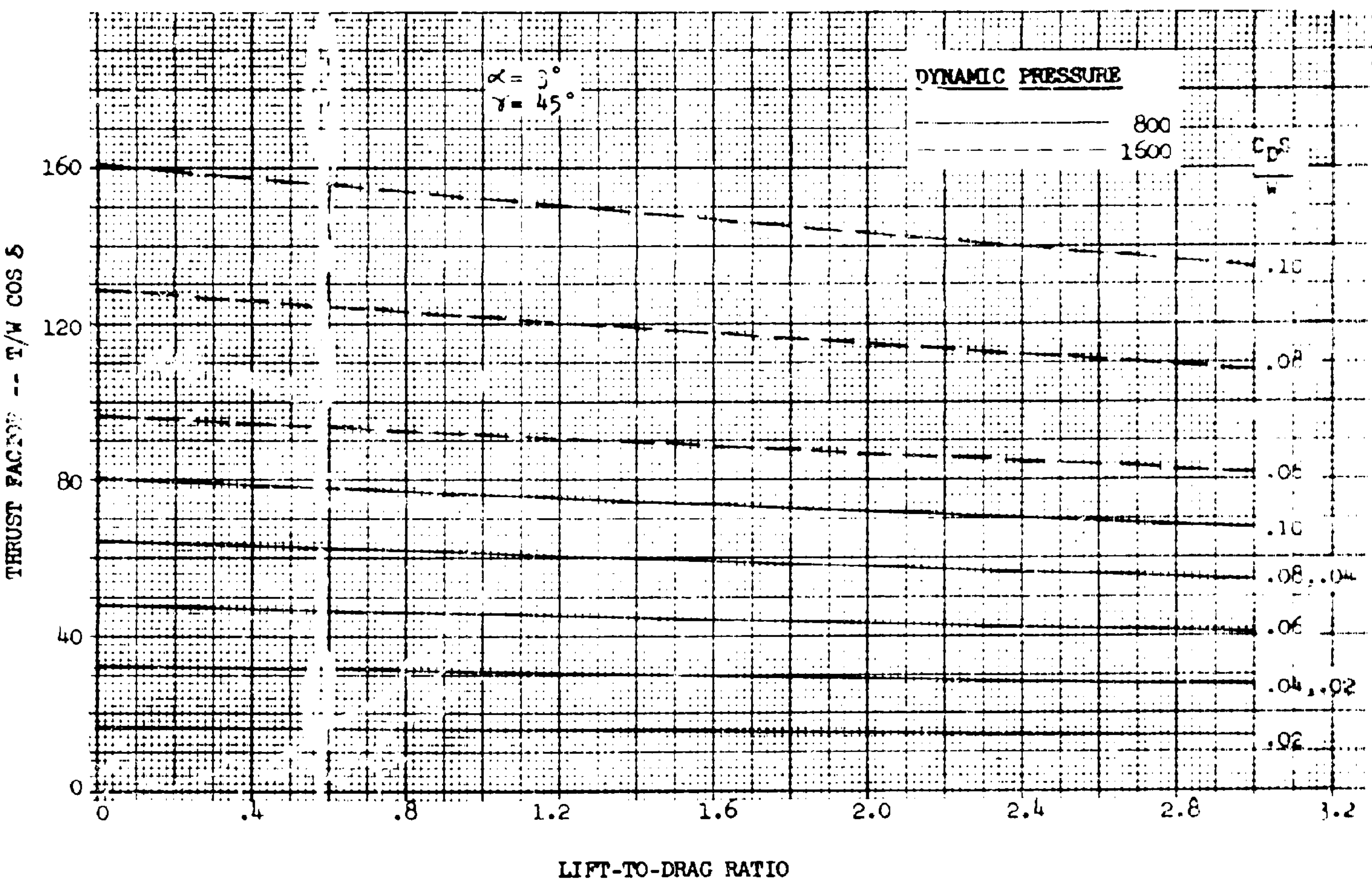


Fig. 66 Separation Criteria - Effect of Lift-to-Drag Ratio

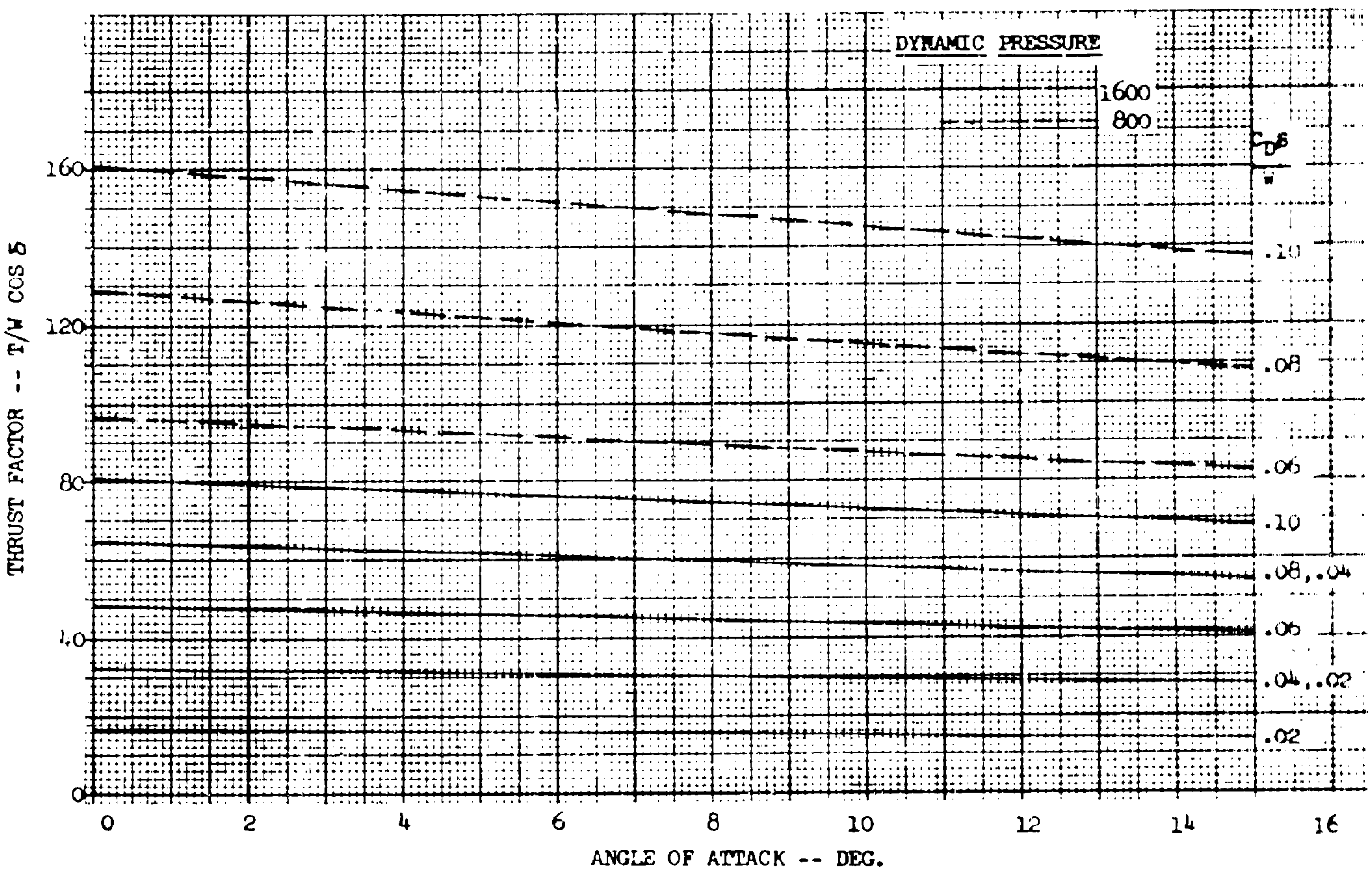


Fig 67 SEPARATION CRITERIA --Effect of Angle of Attack

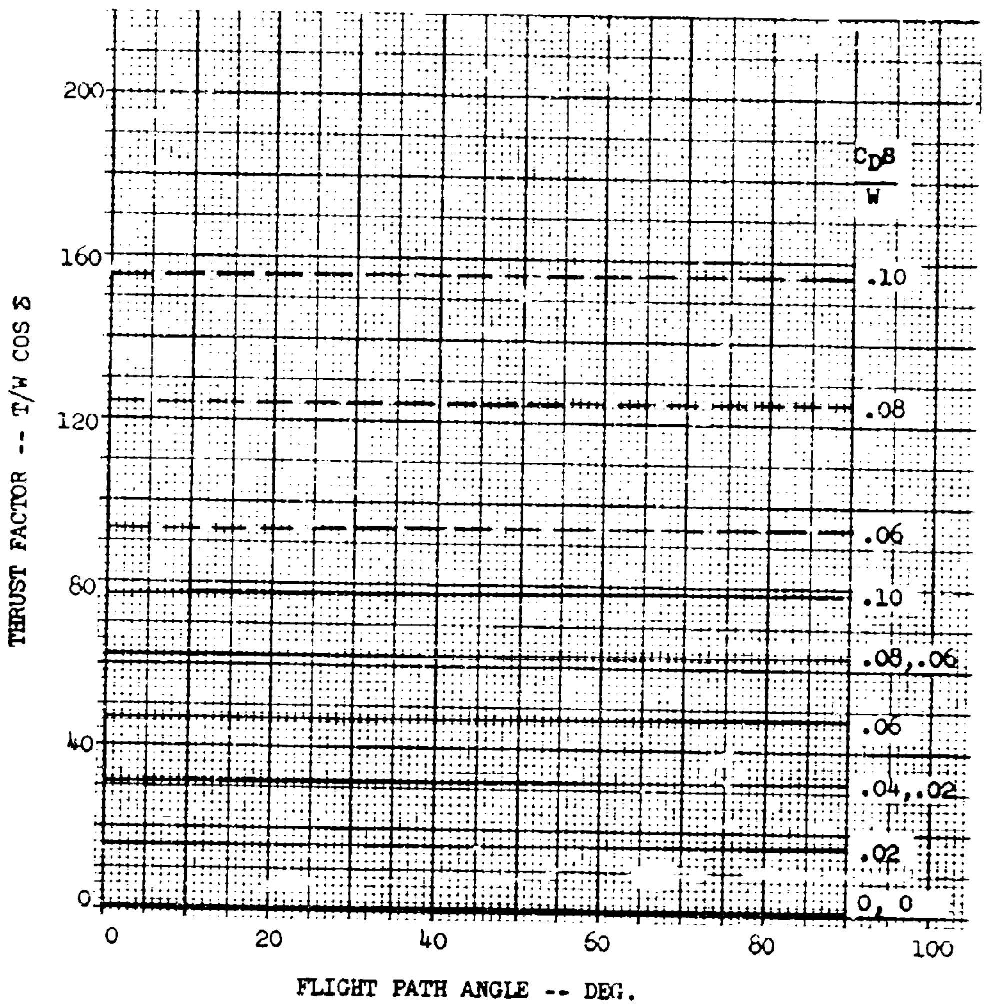


Fig. 68 Separation Criteria - Effect of Flight Path Angle

6.2.2.1 Techniques. The separation distance characteristics between two capsules were obtained using a two degree of freedom trajectory program. This program was a basic two degree of freedom IBM 7090 point mass trajectory program modified to compute the trajectory characteristics of two vehicles and determine their relative separation distance. The modifications included provisions for an initial separation distance between the capsules and a delay time between escape initiation.

6.2.2.2 Parameters. The program described above was used to compute separation characteristics as a function of the parameter variations listed on Tables 11 and 12 and at the initial flight conditions listed in Table 10.

Table 10 Capsule - Capsule Separation - Initial Flight Conditions

Configuration	Flight Path Angle	Altitude	Velocity
Ballistic Body	5°	27,000 ft.	1,800 fps
" "	40°	40,000 ft.	1,800 fps
" "	15°	177,000 ft.	10,000 fps
Lifting Body	5°	27,000 ft.	1,800 fps
" "	45°	40,000 ft.	1,800 fps
" "	15°	177,000 ft.	10,000 fps

Data at subsonic speeds was obtained using the capsule vehicle separation characteristics discussed in Section 4.3.1.

6.2.2.3 Results. An analysis of the large number of computer runs which were made revealed that there were no significant problems in regard to collision using realistic values of the parameters. In order to indicate trends, some typical results have been selected for presentation.

Figure 69 presents data for two ballistic capsules separating from an on-the-pad condition for both an HTOL (γ = 0°) and a VTOHL (γ = 90°) launch. The data is presented in the form of separation distance between the two capsules as a function of time. The effects of delay time and escape rocket thrust loading are shown. With no delay time, the separation distance characteristics remain constant at their initial value since the capsule characteristics are identical. Increasing the thrust loading increases separation distance using a delay time of 0.2 seconds.

Figure 70 presents the effect of initiation delay time on the separation characteristics at hypersonic speeds and at high dynamic pressure for the lifting body capsule. With no delay time the separation distance remains constant due to identical capsule characteristics. Increasing the delay time increases the separation distance.

Figure 71 presents the effect of escape rocket thrust characteristics on separation distance for the lifting body capsule at high dynamic pressure. These results indicate that increasing the thrust level or thrust difference between capsules increases the separation distance.

Figure 72 presents the effect of initial separation distance and escape rocket burn time on separation distance for the lifting body capsule at high dynamic pressure. Increasing the burning time of one of the escape rockets greatly increases the separation distance. Increasing the initial separation distance generally increases the separation distance. If the aft capsule is released first the separation distance tends to increase. If the aft capsule is released last the

TABLE 11

PARAMETER VARIATIONS FOR CAPSULE-CAPSULE SEPARATION BALLISTIC BODY -- INITIAL WEIGHT = 2,710 LBS.

Thrust$_1$-lbs	1^{o}	t_{b_1}-sec.	Thrust$_2$-lbs	2^{o}	t_{b_2}-sec.	x-ft	t-sec
65,000	40	1.0	65,000	40	1.0	50	0
						100	
						50	.1
						100	
						50	.2
						100	
						-50	.1
						-100	
75,000						50	0
							.1
55,000	20						0
							.1
						-50	0
							.1
			55,000	20		50	0
							.1
						-50	0
							.1
		2.0				50	
65,000	40	2.0	65,000	40			

TABLE 12

PARAMETER VARIATIONS FOR CAPSULE-CAPSULE SEPARATION LIFTING BODY -- INITIAL WEIGHT = 2,710 LBS.

$Thrust_1$-lbs	1^o	t_{b_1}-sec.	$Thrust_2$-lbs	2^o	t_{b_2}-sec.	x-ft	t-sec
40,000	40	1.0	40,000	40	1.0	50	0
						100	↓
						50	.1
						100	↓
						50	.2
						100	↓
↓	↓					-50	.1
						-100	
30,000	20					50	0
						↓	.1
						-50	0
			↓	↓	↓	↓	.1
			30,000	20	1.0	50	0
						↓	.1
						-50	0
↓	↓	↓				↓	.1
		2.0	↓	↓		50	.1
40,000	40	↓	40,000	40	↓	↓	↓

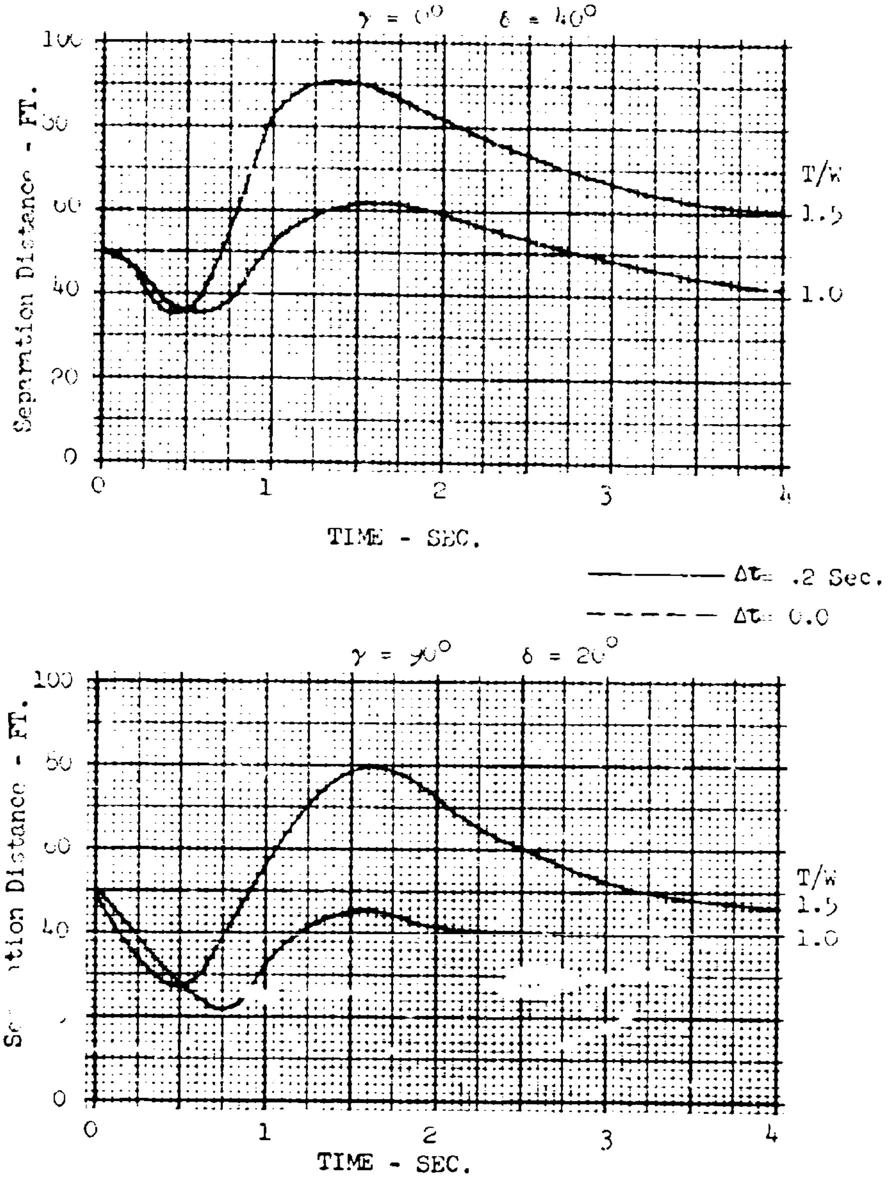


Figure 69 Separation Distance Between Two Ballistic Capsules
V=0; Alt = 0; Burn Time = .1; Δx = 50 Ft.

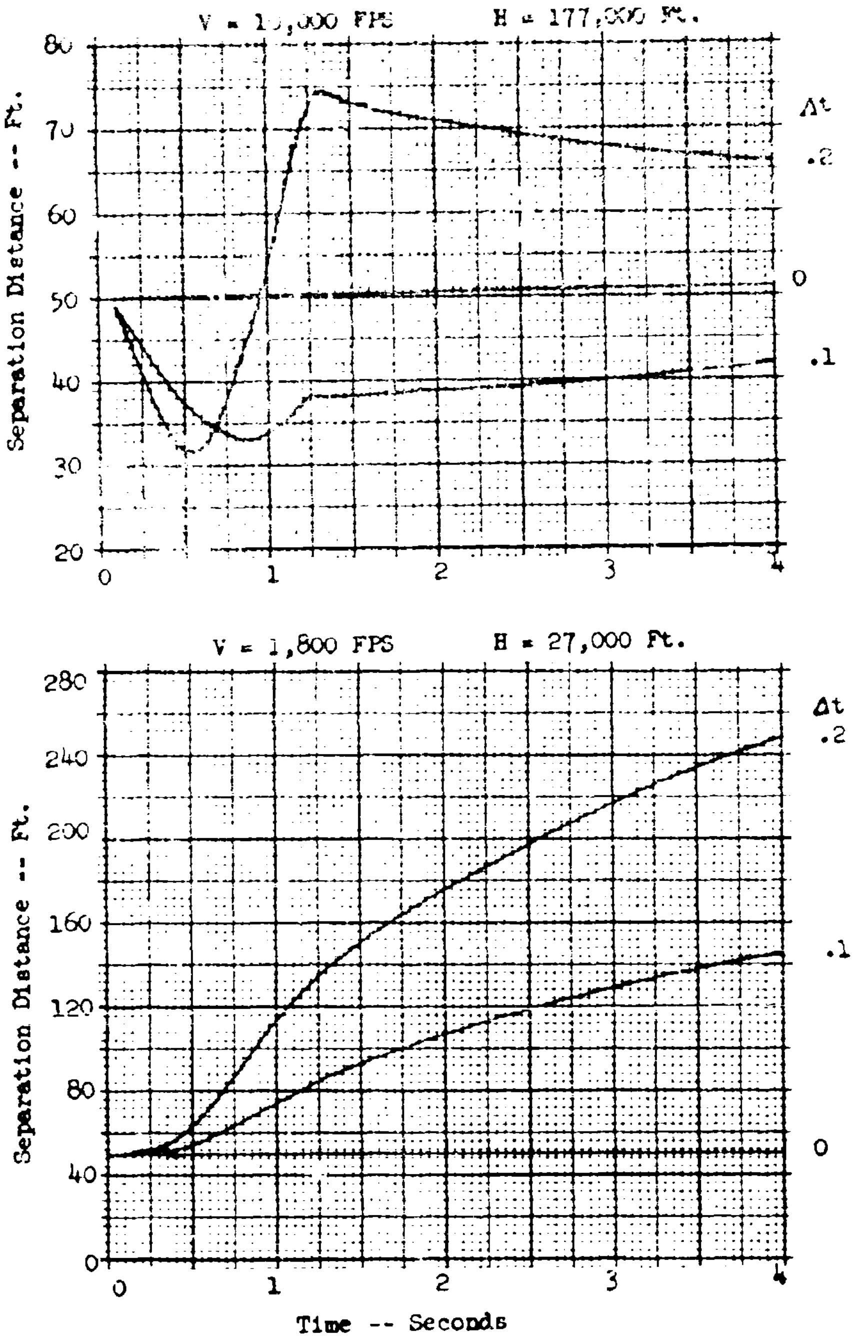
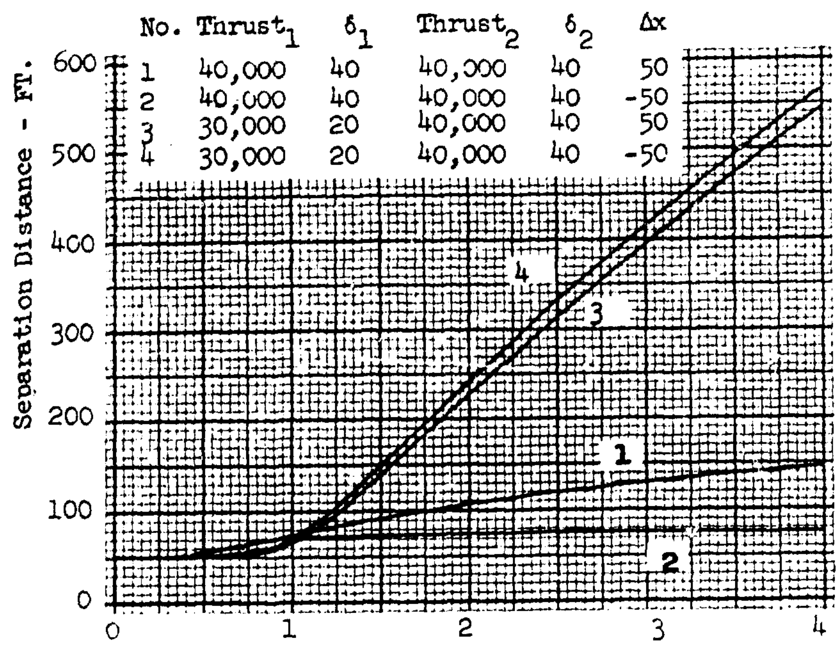


Figure 70 Separation Distance Between Two Lifting Capsules
Supersonic and Hypersonic Speeds Δx = 50 FT.; t_b = 1.0 Sec.



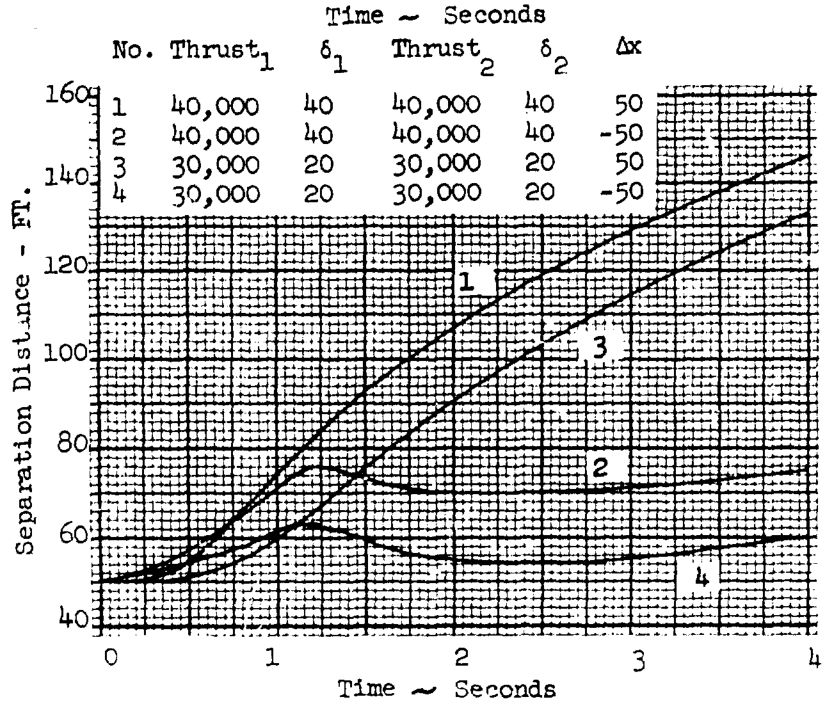


Figure 71. SEPARATION DISTANCE BETWEEN TWO LIFTING CAPSULES
V = 1800 FPS; Altitude = 27,000 ft.; Δt =.1 sec.; Burn Time = t_b = 1 sec.

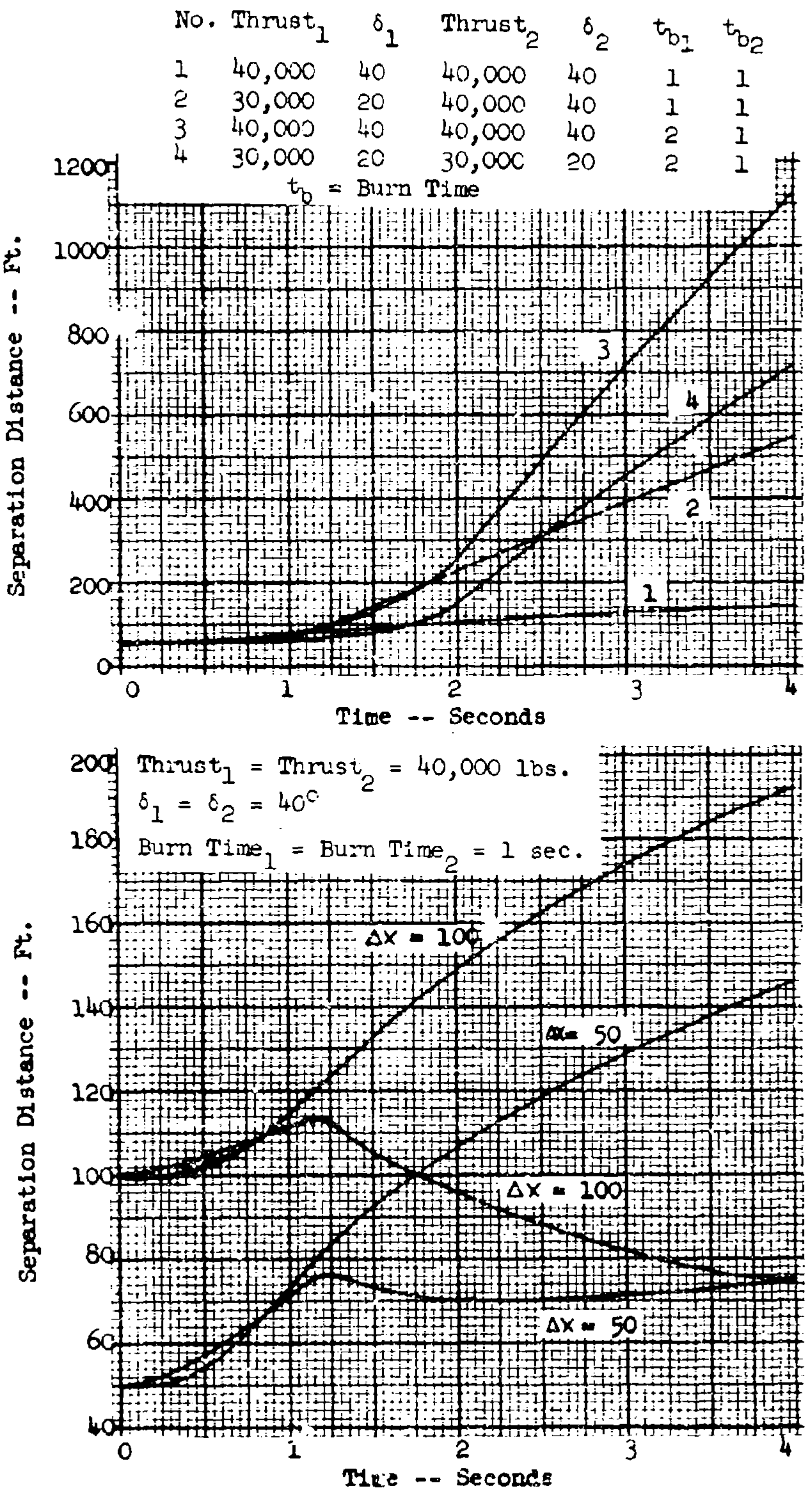


Figure 72 Separation Distance Between Two Lifting Capsules
V = 1800 FPS; Alt = 27,000 FT. Δt =.1Sec.

separation distance tends to decrease slightly after rocket burnout. This is a result of the high drag forces causing the forward capsule, which was released first, to drop back towards the aft capsule.

6.2.2.4 Conclusions. It can be seen from the capsule - capsule separation data discussed above that collision between the two capsules is easier to avoid than achieve. The easiest way to avoid collision appears to be by adjusting thrust loading and thrust angle so that they are different for the two capsules. The general location and sequencing criteria will be discussed in Section 6.2.4.

6.2.3 SEPARATION REQUIREMENTS FROM EXPLOSIONS. It is generally the hazard of explosions which places the requirement of large separation distances in a short time on escape capsules. For this reason a brief investigation was made of capsule separation requirements for some typical explosions.

6.2.3.1 Launch Vehicle Characteristics. Both HTOL and VTOHL launch vehicles were considered. For both vehicles the propellant in each stage was assumed to be liquid hydrogen-liquid oxygen. In the HTOL only the first stage propellant was assumed to explode while in the VTOHL the total propellant was assumed to be available. Explosion characteristics were calculated using the techniques discussed in Section 4.5 for the conditions given in Table 13.

TABLE 13 Launch Vehicle Characteristics for Explosion Calculations

Vehicle	GTOW	Velocity	Altitude	H_2 Weight	O_2 Weight	Propellant Wt.
HTOL	1,000,000	0	0	102,000	508,000	610,000
		1,800	27,000	71,000	356,000	427,000
VTOHL - A	500,000	0	0	71,000	356,000	427,000
		1,800	40,000	52,000	262,000	314,000
- B	2,000,000	0	0	287,000	1,420,000	1,707,000
		1,800	40,000	210,000	1,045,000	1,255,000
- C	6,000,000	0	0	860,000	4,270,000	5,130,000
		1,800	40,000	630,000	3,140,000	3,770,000

NOTE: For HTOL propellant weight is first stage only
For VTOHL propellant weight is first and second stage

6.2.3.2 Explosion Characteristics. For this investigation it was assumed that the escape capsule had an overpressure limit of 5 psi. Figure 73 presents the time and distance characteristics of the 5 psi shock wave for the HTOL vehicle. Figure 74 presents the 5 psi shock wave characteristics for the VTOHL vehicles at sea level and 40,000 feet. As has been previously discussed it is seen that the blast wave propagates at a much higher rate than human tolerance limits would allow an escape capsule to accelerate. It is therefore mandatory that an impending explosion be detected prior to detonation.

6.2.3.3 Escape Requirements. The separation characteristics described in Section 6.2.1 were used in conjunction with the explosion characteristics presented in Figures 73 and 74 to obtain the minimum warning time required to escape without encountering overpressures greater than 5 psi.

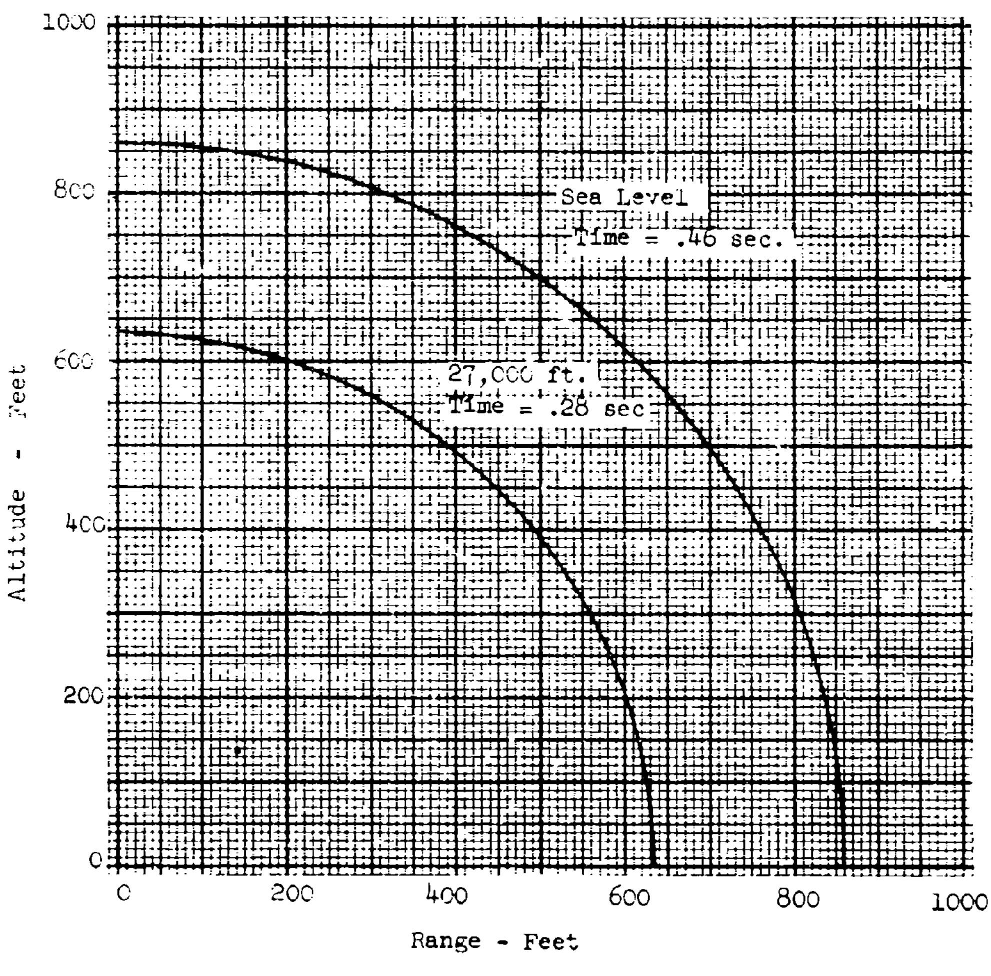


Figure 73. 5 PSI OVERPRESSURE CHARACTERISTICS - HTOL EXPLOSION

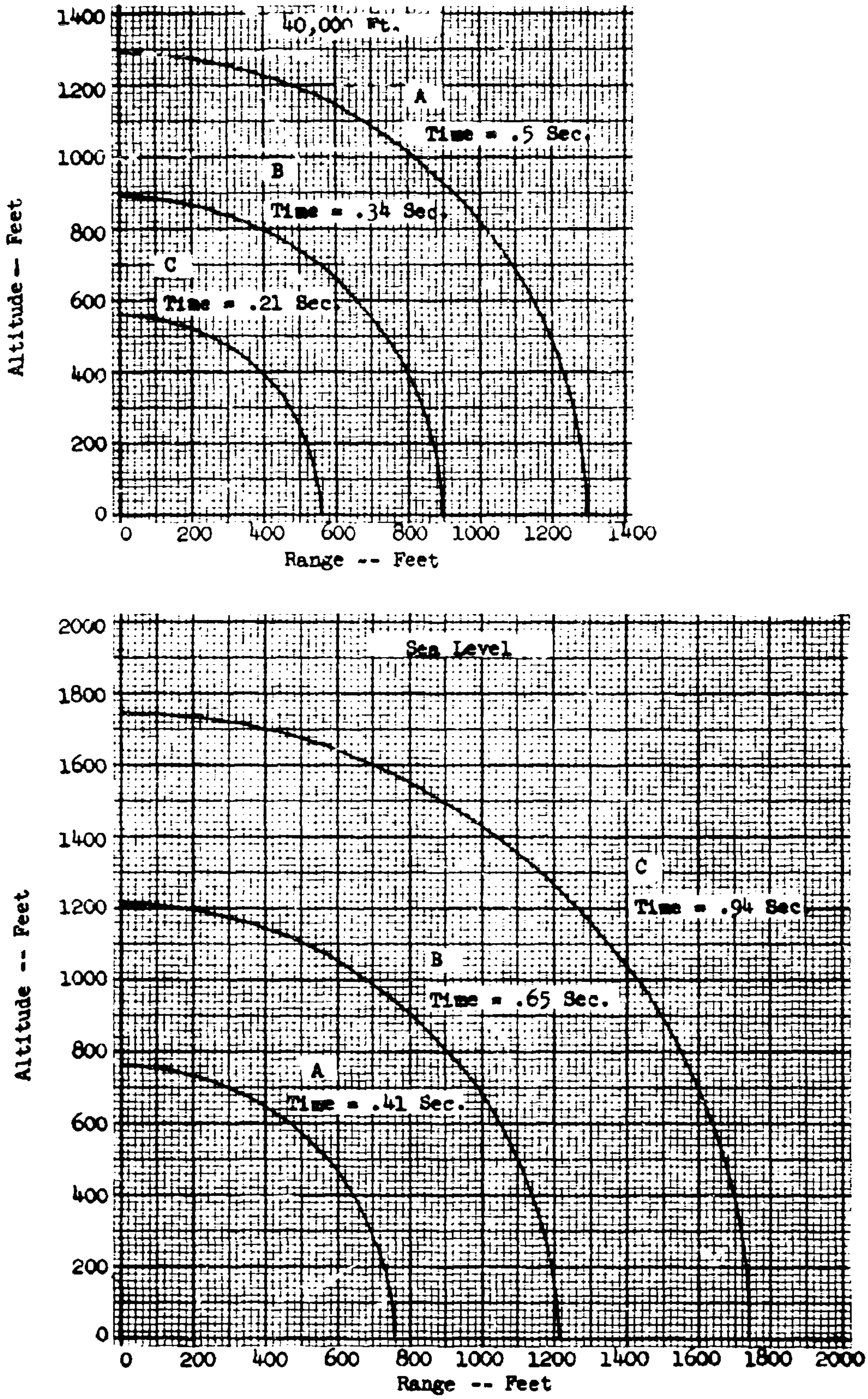


Fig. 74 5 PSI Overpressure Characteristics -- VTOHL Explosion

The resulting warning time data is presented in Figures 75 and 76. Figure 75 shows the effect of thrust loading, burn time and thrust angle on the warning time required for the HTOL vehicle at sea level and 27,000 feet. The maximum warning time requirements range from approximately 1 to 3 seconds depending upon conditions. Figure 76 presents the warning time requirements for the VTOHL vehicles as a function of gross takeoff weight, thrust loading and burn time. As expected, increasing the vehicle size increases the warning time requirements.

6.2.4 LOCATION AND SEQUENCING CHARACTERISTICS. One of the unique factors regarding crew escape for two stage aerospace vehicles having two separated crew compartments is the significance of the location of the crew compartments and the sequencing of escape initiation. These are significant due to the necessity of avoiding a collision.

Prior to examining these unique factors it is significant to examine those factors affecting crew compartment location in general. The location of a crew compartment in an aerospace vehicle must be viewed from the following two aspects:

1. The crew compartment is the control center of the vehicle.
2. The crew compartment serves as the crew escape capsule.

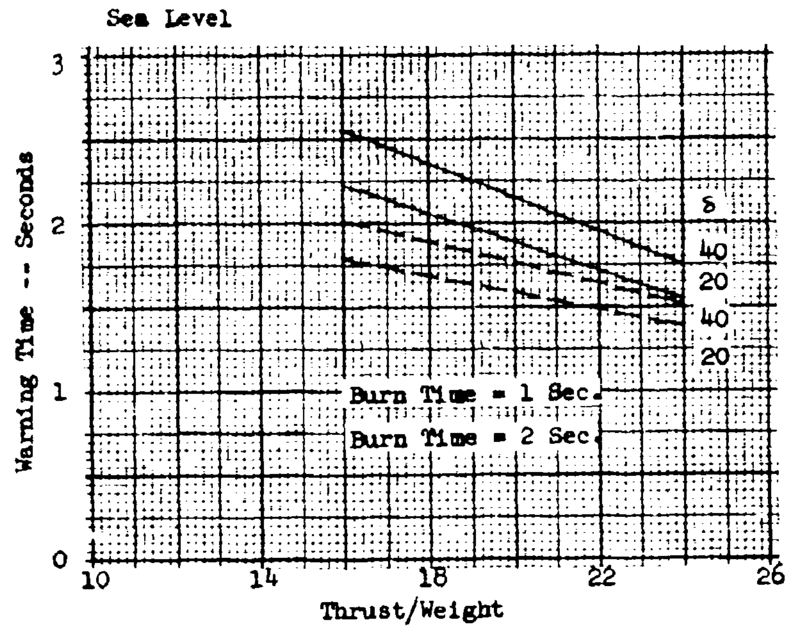
Considered as the control center of the vehicle it is necessary that it be located and sized such that the control function can be carried out. Since the vehicles under consideration in the present study are manually flown at least in the return flight and landing, it is required that adequate outside vision be provided. This dictates a crew compartment location relatively near the nose for each stage.

Considered as a crew escape capsule, the crew compartment should be located such that the escape operation can be performed successfully. This implies that the location not produce serious aerodynamic or structural interference effects.

With the types of two stage vehicles discussed in Section 2, the major displacement between the two capsules will be in the longitudinal direction whether the stage arrangement is tandem or parallel. This occurs in parallel staged configurations since balance considerations generally dictate that the second stage be located such that its center of gravity corresponds to that of the first stage. The separation characteristics discussed in Section 6.2.2 indicate that adequate clearance can be obtained with initial displacements of 50 feet. By adjusting escape rocket thrust loading and thrust angle, adequate clearance could be obtained at even smaller initial displacements.

An additional means of assuring clearance would be adjusting the orientation of the separation plane and rocket thrust direction such that the capsules separated at an angle to the plane of symmetry of the vehicle. This scheme would have the disadvantage of introducing possible asymmetric aerodynamic and structural interference effects.

The sequencing should be such that the aft capsule separates first. This is based on considerations other than collision since thrust loading and thrust



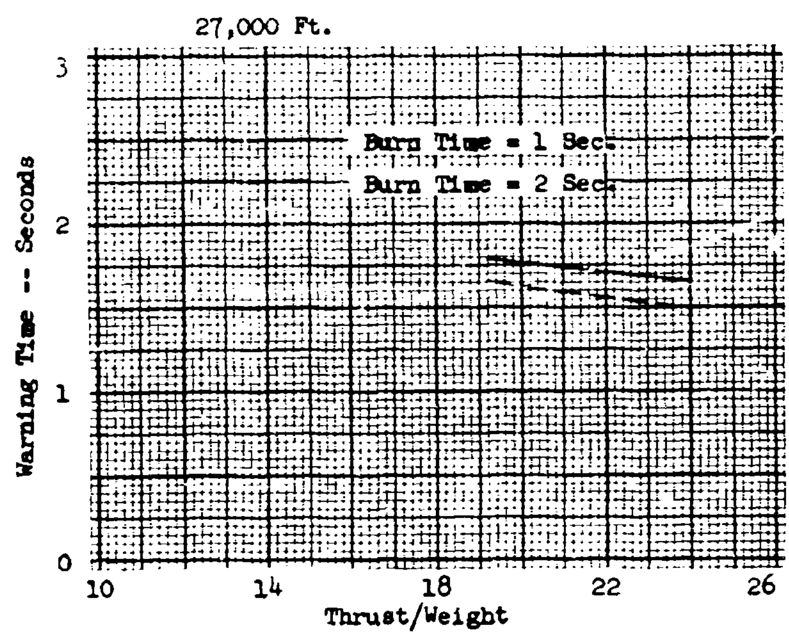
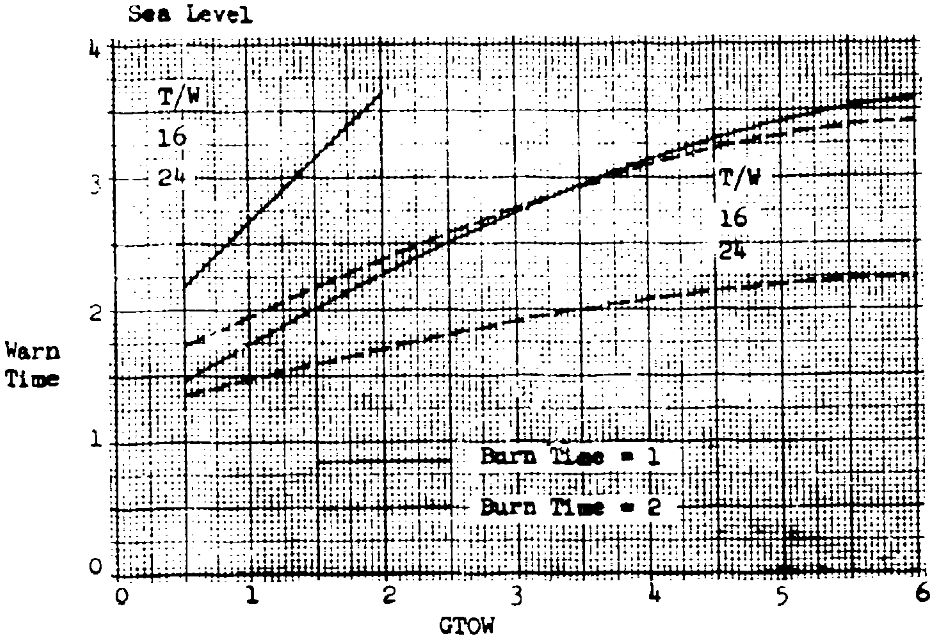


Fig. 75 Minimum Explosion Warning Time Required for a Typical HTOL Vehicle



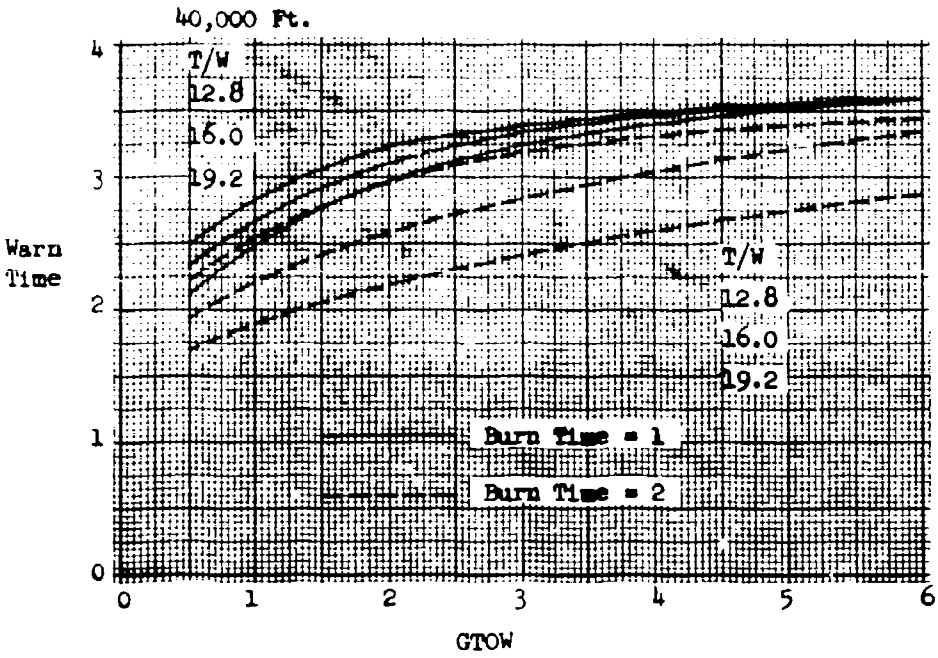


Figure 76 Minimum Explosion Time Required for Typical VTOHL Vehicles

direction characteristics can be easily adjusted to avoid a collision. The first consideration in reaching this decision was the fact that, if the aft capsule separated first, it would avoid the problem of interference effects from the first stage separation. These interference effects could result from the rocket exhaust, aerodynamic flow field effects or even debris. Separation of the aft capsule first is also desirable when considering that the aft capsule is generally closer to the center of a possible explosion. A time delay of 0.1 to 0.2 seconds should be adequate.

Location and sequencing problems may be introduced in the stage separation phase when the second stage is located aft of the first stage. A problem arises if the separation trajectory plane of the first stage escape capsule is the same as or intersects the separation trajectory plane of the second stage. In this situation there is a period of time when the first stage capsule should not be ejected since it would collide with the second stage. The solution to this problem is a delay circuit in the eject system of the first stage capsule which prevents it from ejecting when it might intersect the second stage. This solution does have the disadvantage however of introducing a dead region for the first stage.

In analyzing this dead region, it is significant to note the following ground rules and criteria previously developed:

1. The most severe hazard in terms of onset rate and area of influence is an explosion

2. A warning time is required to escape from an explosion

3. The escape capsule operates at a much higher thrust/weight than the second stage vehicle

The four possible situations which can occur are presented schematically in Figure 77.

In case 1 the warning of an impending explosion in stage 2 is given prior to physical separation. Both capsules separate and escape in a conventional manner.

In case 2 the warning of an impending explosion is given sufficiently ahead of the passage of stage 2 over the first stage capsule that a conventional, separation can occur. The explosion takes place over or beyond the former position of the first stage capsule.

In case 3 the warning occurs when the second stage is in such a position that impact would occur if the first stage was separated immediately. The first stage capsule separation is delayed until passage of the second stage. The first stage capsule then separates.

Case 4 is a special instance of case 3. In case 4 the second stage does not clear the impact region in the time period between warning and explosion. The first stage cannot separate and no escape is possible.

The possibility of case 4 occurring would depend upon the acceleration characteristics of the second stage. The significance of this case would depend upon the results of a criticality study for any given specific design. It must be realized that it is impossible to insure crew safety from all possible malfunctions, e.g., escape system failure. In a given design there is the possibility that the

likelihood of case 4 occurring is less than the likelihood of escape system failure.

It is noted that if the separation trajectory plane of the second stage does not intersect the separation trajectory of the first stage capsule, there is no problem.

CASE 1 - NORMAL PROCEDURE

CASE 2 - WARNING - STAGE 1 SEPARATES - EXPLOSION

CASE 3 - WARNING - STAGE 1 DELAY - STAGE 1 SEPARATES - EXPLOSION

CASE 4 - WARNING - STAGE 1 DELAY - EXPLOSION

FIGURE 77 - POSSIBLE STAGING SITUATIONS

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

1. The two stage manned recoverable aerospace vehicles under consideration in the present study can be classified as either vertical take-off and horizontal landing (VTOHL) or horizontal take-off and horizontal landing (HTOL). Within each of these classifications the stages can be mounted in tandem or parallel.

2. Lower mounted second stages should not be used on HTOL vehicles due to the lack of second stage escape capability at low altitudes.

3. Due to the nature of system and mission hazards, escape capability should be provided for each stage at all times.

4. Fully recoverable capsules are the escape concept offering the greatest escape capability at a minimum penalty in weight and complexity.

5. There are no unique problems in the area of detection, (defined as sensors), resulting from the presence of two separated crew compartments.

6. The fact that most malfunctions necessitating crew escape have a finite onset rate or sequence of malfunctions leading to the catastrophic malfunction leads to the notion of warning time. In many instances this warning time is greater than the minimum human reaction time which means that man can be introduced into escape warning and initiation system.

7. A combination manual/automatic escape warning and initiation system is recommended as the system which provides the fast response characteristics of a machine, which are necessary in certain cases, with the flexibility and decision making capability of man.

8. The cockpit malfunction status display and emergency control console becomes the significant item in the manual/automatic escape warning and initiation system. Similar units should be provided in each crew compartment such that during first stage boost the crew of each stage could monitor performance. This arrangement brings the capabilities of all the men on board into any emergency situation.

9. The manual features of the warning and initiation system must be backed up by the automatic system for fast onset malfunctions and commanded ejections from the ground.

10. Emergency situations should be classified as to degree of severity. Four levels are recommended; ABORT IMMINENT (malfunction indicated), ABORT (malfunction verified), EJECTION IMMINENT and EJECT.

11. Both the ground command posts and the two on-board commanders will have jurisdiction or authority over ejection. Precedence or priority of jurisdiction will vary during the overall mission. While on the ground precedence will generally be vested in ground command posts. After launch or start of take-off precedence will generally be with the pre-selected on-board commander. The other on-board commander will have precedence only at the option of the designated mission commander.

12. The crew compartments should be separated longitudinally. By varying escape rocket thrust or thrust inclination between the two capsules there should be no collision problem.

13. The aft capsule should separate first to minimize the possibility of interference resulting from forward capsule ejection and since the aft capsule is generally closer to the center of a possible explosion.

14. The performance of each stage should be monitored during the staging maneuver.

15. If the separation plane of aft mounted second stage intersects the separation plane of the first stage escape capsule a delay circuit in the first stage ejection system may be necessary to prevent collision between the second stage and the first stage escape capsule.

7.2 RECOMMENDATIONS FOR FURTHER STUDY

1. It is an unlikely fortunate or simple design circumstance where the escape system design provides escape from all conceiveable hazard possibilities. The advent of practicality brings demands of proper trade-offs, weight, space and cost, or optimizations of "values received" for onboard systems. For example, the parachuteless commercial airliner of today does not provide safety against all air hazard possibilities, if it did, the airliner probably would not get off the ground . . . accordingly, information leading to hazard probability distributions and densities in addition to possibilities for hazard occurrence needs deeper investigation today - if trade-offs are to show respectable sensitivities.

2. The problem of realistic formulation of detection requirements for complicated missions can be solved by using a technique combining probability and systems analysis. Further study aimed at developing such a technique is recommended.

3. Continual effort should be expected on advancing the state-of-the-art in sensors.

4. The capability of man in regard to emergency situations should be explored in more depth with the aim of more clearly defining the malfunction status and control display for the cockpits.

5. Explosion characteristics of aerospace vehicles should be better defined since, in general, they impose the most severe requirements on the detection and warning system.

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APPENDIX 1

A Note on Criti ality

Criticality of an item may be defined as the sensitivity of expected mission value to the ith item reliability, that is,

$$C_i = \frac{\partial V}{\partial R_i} \qquad (1)$$

where

V = the expected mission value, and
R_i = the ith item reliability.

By multiplying both sides of (1) above by ΔR_i,

$$C_i \, \Delta R_i = \frac{\partial V}{\partial R_i} \, \Delta R_i .$$

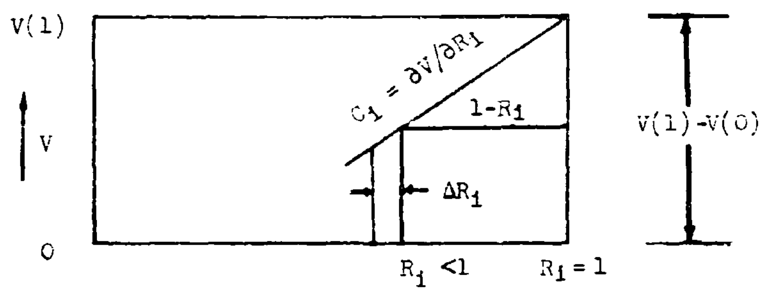
If ΔR_i is taken small enough, or if it happens that the interval of interest of the expected mission value is a linear function of R_i, then expected loss, L_i, under general conditions of reliability degradation,

$$L_i = V(R_i) - V(R_i - \Delta R_i) \quad \text{as} \quad \Delta R_i \longrightarrow 0;$$

and criticality at maximum reliability

$$= V(1) - V(1 - \Delta R_i) ;$$

or graphically as following



In the generation of the malfunction sequence tree, the notion of criticality is most useful in particularizing and arranging top and upper branches. From the upper branches, each of the known antecedent causes and their likely antecedent causes in turn are arranged downward in the direction reverse of their occurrence. See Figure A-1 following. The more completely connected tree incorporates related experience data on lowest level detail hardware, i.e., part failure, effects and onset rates in the part application. The final time-oriented tree with the grouping of cues into appropriate levels per earlier discussions is typically particularized by Figure 26 in the report text.

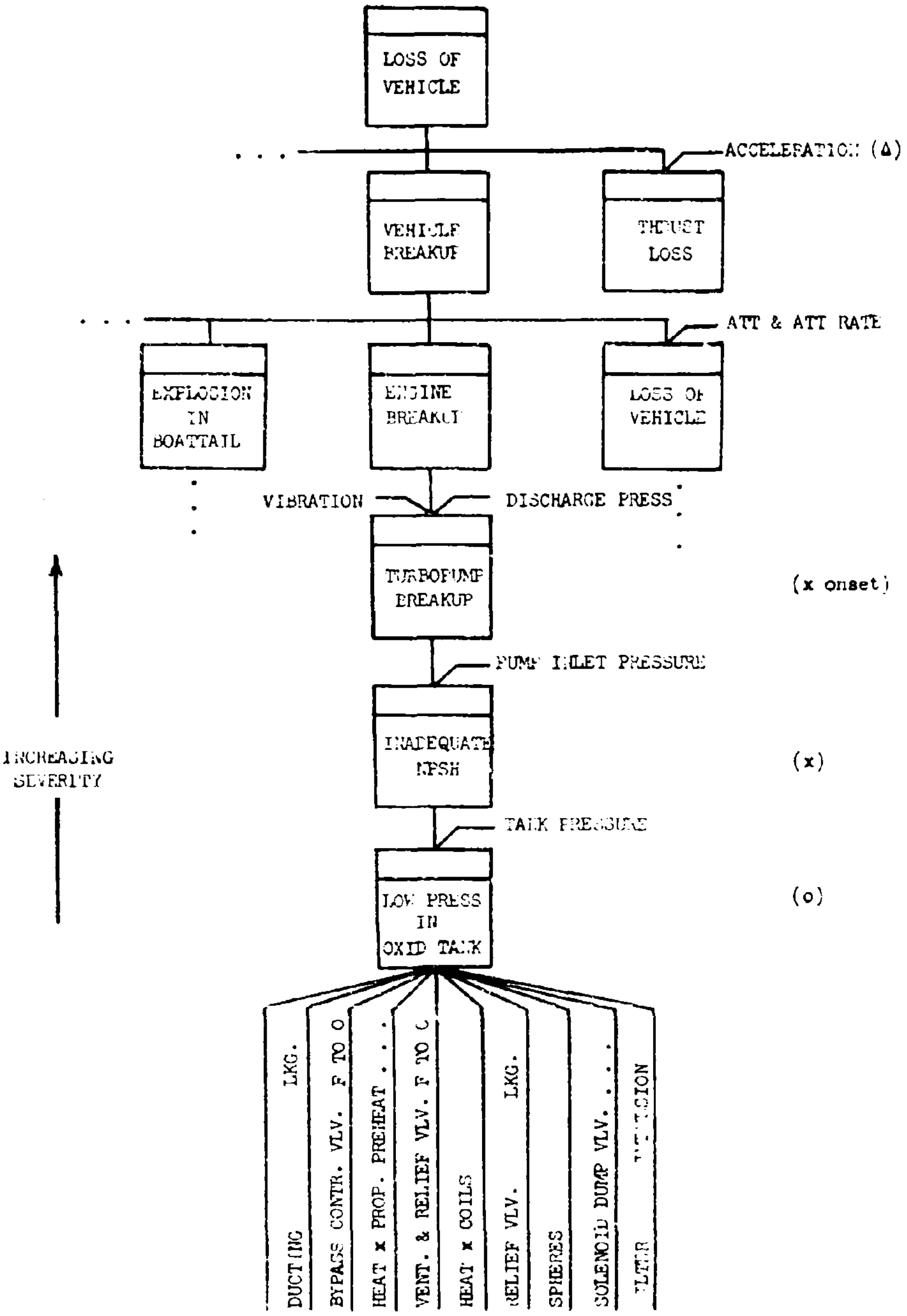


Figure A-1 Typical Malfunction Sequence

APPENDIX 2

A Note on: A General Distribution of Waiting Time to Failure for a Non-Homogeneous Machine in Simple Death Processes. (Mathematically Describable Failure Process)

In this Appendix we describe the hypothetical XTOHL vehicle as being in any one of X, a finite number, of states at time t. We let N denote the absorbing malfunction, i.e., the loss of the vehicle. We let x = 0, and x = 1, 2, . . . , N-1 denote no malfunction, and the set of vehicle malfunction states prior to vehicle loss, respectively. We shall make the at hand post-launch assumption that transitions through the vehicle state or malfunction state space occur monotonic only toward vehicle loss, state N. This means that we assume no time available for malfunction repair, and repair is not attempted.

DISCUSSION

1. We may write in probability terms: $P(X = x) = P$ (state x). We note that we shall be interested in

$P_x(t) = P$ (state x at time t), generally, and

$P_N(t) = P$ (state N at time t), particularly.

Also, we will use the definition

$$P_N(t, t + \Delta t) = P[(t < \tau < t + \Delta t)/(\tau > t)] = g_N(t, t + \Delta t),$$

where τ is the waiting time to vehicle loss.

2. According to the assumptions foregoing, then, the set of vehicle, or perhaps better, system state transitions to vehicle loss may be diagrammed as follows:

$$0 \longrightarrow 1 \longrightarrow 2 \longrightarrow \ . \ . \ . \quad N-1 \longrightarrow N,$$

where N is the absorbing malfunction, vehicle loss.

3. Now for the foregoing set of transitions we observe the following postulates for changes of state in the time space $T = \{>0\}$:

System State:	Number of Changes	Probability: $P_x(t, t + \Delta t)$
x-n	$n \geq 2$	$P_{x-n}(t)\, o(\Delta t)$
x-1	1	$P_{x-1}(t)\,(\gamma_{x-1}\Delta t + o(\Delta t))$
x	0	$P_x(t)\,(1 - \gamma_x \Delta t - o(\Delta t))$

where $\frac{o(\Delta t)}{\Delta t} \longrightarrow 0$ as $t \longrightarrow 0$ and, $0 \leq x \leq N-1$.

4. Next, we consider additional state transition postulates as follows:

At any time t, the system being in state x, there exists the probability that during $(t, t + \Delta t)$ the transition:

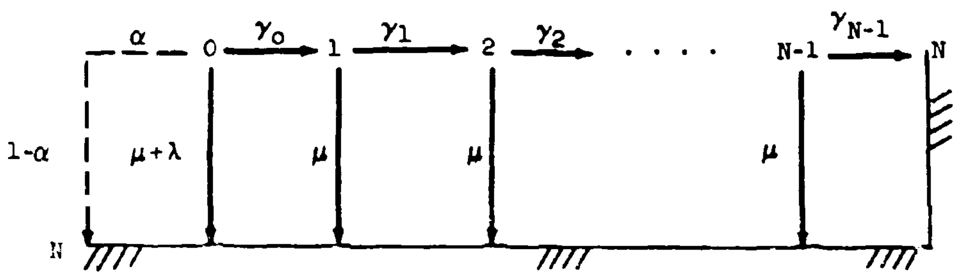
(a) $x \longrightarrow N$ occurs, proportional to $\mu\Delta t + o(\Delta t)$;

(b) $(x = 0) \longrightarrow N$ occurs, proportional to $\lambda\Delta t + o(\Delta t)$.

5. Setting the initial conditions for the process as:

$$P_x(0) = \left.\begin{array}{ll} \alpha & x = 0 \\ 0 & 1 \leq x \leq N-1 \\ 1-\alpha & x = N \end{array}\right\} \quad 0 < \alpha < 1,$$

we may diagram sets of system state transitions to vehicle loss as following:



6. In accordance with all preceding and setting $\gamma_x = \gamma$ i.e., stationary for $x < N$,

$$P_N(t, t + \Delta t) = \sum_{x=0}^{N-1} P_x(t)\,\mu\Delta t + O(\Delta t) + P_o(t)\,\lambda\Delta t + P_{N-1}(t)\,\gamma\Delta t.$$

Dividing through by Δt as $\Delta t \longrightarrow 0$

$$P_N(t) = \lambda P_o(t) + \mu \sum_{x=0}^{N-1} P_x(t) + \gamma P_{x-1}(t) = g_N(t),$$

the probability density function of waiting time to vehicle loss.

7. To continue it is necessary to determine $P_x(t)$. We observe in the diagram, for $x > 0$,

$$P_x(t, t + \Delta t) + P_x(t)(1-\gamma\Delta t - \mu\Delta t) + P_{x-1}(t)\,\gamma\Delta t + o(\Delta t).$$

Transposing terms appropriately, and using

$$\lim_{\Delta t \to 0} \frac{F(t + \Delta t) - F(t)}{\Delta t} = \frac{dF}{dt} = F'(t),$$

$$P'_x(t) = -(\gamma + \mu)\,P_x(t) + \gamma\,P_{x-1}(t).$$

More particularly,

$$P_1'(t) + -(\gamma + \mu) P_1(t) + \gamma P_o(t).$$

For x = 0, we obtain

$$P_o(t, t + \Delta t) = P_o(t)\,[1 - \gamma\Delta t - \mu\Delta t - \lambda\Delta t - o(\Delta t)],$$

$$P_o'(t) = -(\gamma + \mu + \lambda) P_o(t).$$

Solutions to the above differential equations may be obtained by various methods.

8. To continue, if we choose a method of Laplace transformation for solution of the differential equations, we let $P_x(s) = \mathcal{L}\,[P_x(t)]$.

Since

$$P_o'(t) = -(\mu + \gamma + \lambda) P_o(t),$$

$$-P_o(0) + s P_o(s) = -(\mu + \gamma + \lambda) P_o(s),$$

$$s P_o(s) - \alpha = -(\mu + \gamma + \lambda) P_o(s), \text{ and}$$

$$P_o(s) = \alpha / [s + (\mu + \gamma + \lambda)].$$

Inversion

$$P_o(t) = \alpha e^{-(\mu + \gamma + \lambda)t}.$$

Since

$$P_x'(t) = -(\mu + \gamma) P_x(t) + \gamma) P_x(t) + \gamma P_{x-1}(t)$$

$$-P_x(0) + s P_x(s) = -(\mu + \gamma) P_x(s) + \gamma P_{x-1}(s)$$

$$P_x(s) = \gamma \frac{P_{x-1}(s)}{s + (\gamma + \mu)}$$

More particularly, for x = 1,

$$P_1(s) = \frac{\gamma P_o(s)}{s + (\gamma + \mu)} = \frac{\gamma}{[s + \gamma + \mu]^2}$$

Accordingly for $1 \leq x \leq N-1$,

$$P_x(s) = \frac{\gamma^x}{[s + (\gamma + \mu)]^{x+1}}$$

Inversion

$$P_x(t) = \frac{(\gamma t)^x e^{-(\gamma + \mu)t}}{x!}$$

9. Since

$$g_N(t) = \lambda P_o(t) + \mu \sum_{x=0}^{n-1} P_x(t) + \gamma P_{N-1}(t),$$

$$g_N(t) = e^{-\mu t}\left[\alpha\lambda e^{-(\lambda+\gamma)t} + \mu \sum_{x=0}^{N-1} \frac{(\gamma t)^x}{x!} e^{-\gamma t} + \frac{\gamma(\gamma t)^{N-1}}{(N-1)!} e^{-\gamma t}\right]$$

10. The distribution function of waiting times to vehicle loss, $G_N(t)$

$$G_N(t) = \int_0^t g_N(t)\,dt$$

$$= \alpha\gamma \int_0^t e^{-(\mu+\lambda+\gamma)t}\,dt + \int_0^t e^{-\mu t}\left[\mu \sum_{x=0}^{N-1} \frac{(\gamma t)^x}{x!} e^{-\gamma t} + \frac{\gamma(\gamma t)^{N-1}}{(N-1)!} e^{-\gamma t}\right] dt$$

$$= \frac{\alpha\lambda}{\mu+\lambda+\gamma}\left[1 - e^{-(\mu+\lambda+\gamma)t}\right] + 1 - e^{-\mu t}\left[1 - P(N, \gamma t)\right]$$

where

$$P(N, \gamma t) = \frac{1}{(N-1)!}\int_0^t \gamma(\gamma t)^{N-1} e^{-\gamma t}\,dt = \sum_{x=N}^{\infty} \frac{(\gamma t)^x}{x!} e^{-\gamma t}$$

If we are interested in the corresponding vehicle integrity function, $R(t)$

$$R(t) = 1 - G_N(t)$$

$$= \frac{\alpha\lambda}{\mu+\lambda+\gamma} - \left[e^{-(\mu+\lambda+\gamma)t} - 1\right] + e^{-\mu t}\left[1 - P(N, \gamma t)\right].$$

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13. ABSTRACT: Previous studies have investigated escape from aerospace vehicles in the general aspects of escape concepts, configurations, systems and performance for single crew compartments. At hand is the concept of two stage manned recoverable aerospace vehicles with a crew compartment in each stage. In this study the detection, initiation and separation phases of escape were investigated to determine the unique problems, if any, in these phases resulting from the presence of two separated crew compartments. The basic mission was an orbital mission, and the basic configuration classes were vertical take-off and landing (VTOHL) and horizontal take-off and landing (HTOL). Generalized hazards analysis studies were made for each configuration class considering system hazards and mission effects. Escape concepts ranging from ejection seats to fully recoverable capsules were reviewed for applicability to the present problem with the fully recoverable capsule being selected. A combination manual/automatic escape initiation system was selected as the most promising for these advanced concept vehicles. A cockpit malfunction status display and emergency control console was conceptually designed. This system, called the Malfunction Warning Display, would be in each compartment and prior to staging each compartment would monitor boost performance, making the most use of the flexibility and decision making capability of the men in each crew compartment. Separation trajectory characteristics were investigated leading to the establishment of crew compartment location and ejection sequencing criteria.

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